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METHOD AND APPARATUS FOR EXTENDING EQUIPMENT UPTIME IN ION IMPLANTATION

CROSS REFERENCE TO RELATED APPLICATIONS

The following patent applications, herein incorporated by reference, are related to the present application: International application no. PCT/US03/20197, filed June 26, 2003: "An ion implantation device and a method of semiconductor manufacturing by the implantation of boron hydride cluster ions", inventors Horsky *et al.*, and U.S. Patent Application No. 10/183,768, "Electron impact ion source", submitted June 26, 2002, inventor T. N. Horsky.

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Assignee: SemEquip, Inc., 34 Sullivan Road Suite 21, Billerica, MA 01816.

Reference Documents

1. Lee, U.S. patent 5,785,796, "Vacuum processing apparatus, vacuum processing method, and method for cleaning the vacuum processing apparatus", issued July 28, 1998.

2. Shang *et al.*, U.S. patent 5,788,778, "Deposition chamber cleaning technique using a high power remote excitation source", issued August 4, 1998.

3. Tsukamoto, U.S. patent 6,060,034, "Abatement system for ClF_3 containing exhaust gases", issued May 9, 2000.

4. Goto *et al.*, U.S. Patent 6,013,332, "Boron doping by decaborane", issued January 11, 2000.

5. Smith *et al.*, U.S. patent 6,150,628, "Toroidal low-field reactive gas source", issued Nov 21, 2000; also U.S. Patent 6,486,431, issued Nov 26, 2002; and USPTO patent applications 20020125225 and 20020125226, both filed May 10, 2002, also entitled Toroidal low-field reactive gas source.

6. Horsky, U.S. patent 6,452,338, "Electron beam ion source with integral low-temperature vaporizer", issued September 17, 2002.

7. Rosner *et al.*, "Kinetics of the attack of refractory solids by atomic and molecular fluorine", J. Phys. Chem 75(5), pp. 308-317 (1971).

I. Background of the Invention

I.1 Field of the Invention

The present invention relates to a method and system of ion implantation in which one or more dopant-containing materials are ionized in an ion source, and a method and apparatus for operating said ion source for use in the ion implantation of semiconductor substrates, and substrates for flat panel displays.

I.2 Description of the Prior Art

The Ion Implantation Process

The fabrication of semiconductor devices involves, in part, the introduction of impurities into the semiconductor substrate to form doped regions. The impurity elements are selected to bond with the semiconductor material to create electrical carriers, thus altering the electrical conductivity of the semiconductor material. The electrical carriers can either be electrons (generated by N-type dopants) or "holes" (*i.e.*, the absence of an electron), generated by P-type dopants. The concentration of dopant impurities so introduced determines the electrical conductivity of the doped region. Many such N- and P-type impurity regions must be created to form transistor structures, isolation structures and other such electronic structures, which collectively function as a semiconductor device.

The conventional method of introducing dopants into a semiconductor substrate is by ion implantation. In ion implantation, a feed material containing the desired element is introduced into an ion source and energy is introduced to ionize the feed material, creating ions which contain the dopant element (for example, in silicon the elements As, P, and Sb are *donors* or N-type dopants, while B and In are *acceptors* or P-type dopants). An accelerating electric field is provided to extract and accelerate the typically positively-charged ions out of the ion source, for example, by an ion extraction electrode, thus creating an ion beam. Then, mass analysis is used to select the species to be implanted, as is known in the art, and the mass-analyzed ion beam is ultimately directed into a semiconductor substrate or workpiece.

Similar technology is used in the fabrication of flat-panel displays (FPD's) which incorporate on-substrate driver circuitry to operate the thin-film transistors which populate the displays. Ion implantation systems used in the manufacturing of FPD's incorporate physically large ion sources which create large-area ion beams of boron, phosphorus and arsenic-containing materials, for example, although most FPD implanters do not mass-analyze the ion beam prior to its reaching the substrate.

Contamination Issues in Ion Implanters

In general, ion beams of N-type dopants, such as P or As, should not contain any significant portion of P-type dopants, and ion beams of P-type dopants, such as B or In, should not contain any significant portion of N-type dopants. Such a condition is called "cross-contamination" and is undesirable for processing semiconductors. Cross-contamination can occur when source feed materials accumulate in the ion source, and the source feed material is then changed, for example, when first running elemental phosphorus feed material to generate a N-type P^+ beam, and then switching to BF_3 gas to generate a P-type BF_2^+ beam.

A serious contamination effect occurs when feed materials accumulate within the ion source so that they interfere with the successful operation of the source. Such a condition invariably calls for removal of the ion source and related components (such as the extraction electrode) for cleaning or replacement, resulting in an extended "down" time of the ion implanter.

Typically, the ion sources used in ion implanters for device wafer manufacturing are

"hot" sources, that is, they operate by sustaining an arc discharge and generating a dense plasma; the ionization chamber of such a "hot" source can reach an operating temperature of 800C or higher, in many cases substantially reducing the accumulation of solid deposits. In addition, the use of BF_3 in such sources to generate boron-containing ion beams further reduces deposits, since in the generation of a BF_3 plasma, copious amounts of fluorine ions are generated; flourine can etch the walls of the ion source, and in particular, recover deposited boron through the chemical production of gaseous BF_3.

Cold ion sources are used in applications where: *i)* the design of the ion source includes permanent magnets which must be kept below their Curie temperature, or/and *ii)* the ion source is designed to use thermally-sensitive feed materials which break down when exposed to hot surfaces. Cold ion sources suffer more from the deposition of feed materials than do hot sources. The use of halogenated feed materials, however, helps reduce deposits to some extent. However, in certain cases, non-halogen materials, such as hydrides, are preferred over halogenated compounds for process reasons. For non-halogen applications, feed materials, such as gaseous B_2H_6, AsH_3, and PH_3, are used. In some cases, elemental As and P are used, although these materials are vaporized materials which readily condense in cold sources; therefore, they tend to form contaminating deposits. The use of these gases in cold ion sources results in increased materials deposition and requires the ion source to be removed and cleaned, sometimes frequently. Cold ion sources which use B_2H_6 and PH_3 are in common use today in FPD implantation tools. These sources suffer from cross-contamination (between N- and P-type dopants) and also from particle formation due to the presence of deposits. When transported to the substrate, particles negatively impact yield, and cross-contamination effects have historically forced FPD manufacturers to use dedicated implanters, one for N-type, and one for P-type. Thus, there is a critical need for in-situ cleaning of FPD ion sources to increase yield and to reduce cost of ownership.

Boron Hydrides

Recently, boron hydride materials, such as $B_{10}H_{14}$ (decaborane) and $B_{18}H_{22}$ (octadecaborane), have attracted interest as ion implantation source materials. Under

the right conditions, these materials form the ions $B_{10}H_x^+$, $B_{10}H_x^-$, $B_{18}H_x^+$, and $B_{18}H_x^-$, which when implanted enable very shallow, high dose P-type implants for shallow junction formation in CMOS manufacturing. Since these materials are solid at room temperature, they must be vaporized and flowed into the ion source for ionization. They are low-temperature materials (*e.g.,* decaborane melts at 100C, and has a vapor pressure of approximately 0.2 Torr at room temperature; also, decaborane dissociates above 350C), and hence must be used in a cold ion source. They are fragile molecules which are easily dissociated, for example, in hot plasma sources.

Contamination issues of boron hydrides

Boron hydrides, such as decaborane and octadecaborane, present a severe deposition problem when used in ion sources, due to their propensity for readily dissociating within the ion source. These materials are used extensively in Bernas-style ion sources and also in electron-impact ("soft") ionization sources. It is known that boron-containing deposits accumulate within the ion sources at a substantial rate. In fact, a reasonable model for estimating the buildup rate is to assume that at least half of the boron hydride vapor introduced into the source stays in the source as dissociated material. Eventually, depending on the design of the ion source, these buildups interfere with the operation of the source and necessitate removal and cleaning of the ion source.

Contamination of the extraction electrode is also a problem when using these materials. Both direct ion beam strike and condensed vapor can degrade operation of the ion beam formation optics, since these boron-containing layers appear to be electrically insulating. Once electrically insulating layers are deposited, they charge up and create vacuum discharges, or "glitches", upon breakdown. This creates instabilities in the ion beam current and can contribute to the creation of particles.

II. Summary of the Invention

It is an object of this invention to provide a method of operating an ion source which increases service lifetime and reduces equipment down time.

It is also an object of this invention to define in-situ cleaning procedures for an ion source which chemically removes deposits, increasing service lifetime and performance.

It is a further object of this invention to define an actively heated ion extraction electrode which consists of a material which reduces the frequency and occurrence of vacuum discharges, preferably a metal.

These and other innovations of the invention may include one or more of the following features:

An inert co-gas is flowed into the ion source in addition to boron hydride vapor; vapor flow into the ion source is maintained to less than 1 sccm; vapor flow into the ion source is maintained to less than 0.5 sccm; the ion source is fabricated of aluminum; the ion source is cleaned through exposure to reactive NF_3 products, such as atomic flourine, F or molecular fluorine, F_2; the atomic or molecular fluorine is injected into the ion source from a remote plasma source; the ion source is cleaned through exposure to ClF_3; the extraction electrode is fabricated of aluminum; the extraction electrode is fabricated of molybdenum; the front face of the extraction electrode is devoid of sharp or rough features; the plates of the extraction electrode are actively temperature controlled; the plates of the extraction electrode are actively heated; said heating mechanism is radiative; said heating mechanism is resistive.

While the use of boron hydrides to form "cluster" ion beams such as $B_{10}H_x^+$ and $B_{18}H_x^+$ is very attractive for shallow junction formation, special means to ionize and transport these large molecules are required. For example, U.S. patents 6,288,403 and 6,452,338 describe ion sources which have successfully produced decaborane ion beams. However, such decaborane ion sources have not been known to be used commercially due in large part to their observed short service life, as compared to other commercial ion sources used in ion implantation. This short service life is primarily due to the accumulation of boron-containing deposits within the ion source, and the deposition of insulating coatings on the ion extraction electrode, which lead to beam instabilities. In this invention, we disclose means to substantially reduce the deposition of such deposits in the ion source and on the ion extraction electrode, and we also disclose means to clean deposits on these components without removing them from the ion implanter, *i.e., in-situ.* This invention therefore enables the commercial use of boron hydride cluster beams in semiconductor manufacturing with long service lifetime.

Deposition Model

It is a generally observed principle of physics that when two objects interact, there can be more than one outcome. Furthermore, one can assign probabilities or likelihoods to each outcome such that, when all possible outcomes are considered, the sum of their individual probabilities is 100%. In atomic and molecular physics such possible outcomes are sometimes called *channels* and the probability associated with each interaction *channel* is called a *cross section*. More precisely, the likelihood of two particles (say, an electron and a gas molecule) interacting with each other at all is the *total cross section,* while the likelihoods of certain types of interactions (such as the interaction represented by the electron attaching itself to the gas molecule thus forming a negative ion, or by removing an electron from the gas molecule thus forming a positive ion, or by dissociating the molecule into fragments, or by elastically scattering with no chemical change of the molecule) the *partial cross sections.*

This state of affairs can be represented by a mathematical relation which expresses the total cross section σ_T as the sum of its *i* partial cross sections:

(1) $\sigma_T = \sigma_1 + \sigma_2 + \sigma_3 + \ldots \sigma_i$, or

(2) $\sigma_T = \sum \sigma_i$.

The ion sources used in ion implanters typically display modest ionization fractions. That is, only a small fraction (from a few per cent to a few tens of per cent) of the gas or vapor fed into the ion source is ionized. The rest of the gas or vapor typically leaves the source in the gas phase, either in its original state or in some other neutral state. That is, the ionization cross section is much smaller than the total cross section. Of course, some of the gas components can stay in the ion source as deposited materials, although this tends to be a small percentage of the total for the commonly used implantation feed materials. While vaporized feed materials such as elemental As or P more readily produce deposits than do gaseous feed materials, the vapor tends to stay in the gas phase if the walls of the ion source are at a higher temperature than the vaporizer, and do not pose a severe deposition risk.

In the case of the boron hydrides, however, it seems the total cross section representing interaction with the ionizing mechanism (*i.e.*, the electrons introduced into the ion source) is large, the ionization cross section is small, and by far the largest cross

section represents the channel for dissociation of the boron hydride molecules into non-volatile fragments, which then *remain* in the ion source. If this thesis is accurate, then deposition of boron-containing fragments in the source is a fundamental phenomenon which would be observed in any type of ion source, making its solution of broad, critical interest to the semiconductor manufacturing industry.

A corollary to the above thesis is that less material is deposited in the source as the vapor flow is reduced; that is, we would expect the deposition rate to be roughly proportional to the flow rate. To test this corollary, we ran decaborane in a novel ion source (see International Application no. PCT/US03/20197, incorporated by reference; also see Fig. 3a and 3b) under long-term testing. Although the operation of this source is disclosed in the referenced application, for convenience we now give a brief description.

Novel Ion Source

The novel ion source is an electron-impact ion source which is fully temperature-controlled. Instead of striking an arc-discharge plasma to create ions, the ion source of the present invention uses a "soft" electron-impact ionization of the process gas by energetic electrons injected in the form of one or more focused electron beams. The "soft" ionization process preserves the large molecules so that ionized clusters are formed. As seen in Fig. 3a and Fig. 3b, solid boron hydride is heated in a vaporizer and flowed through a vapor conduit to a metal chamber, *i.e.,* the ionization chamber. An electron gun located external to the ionization chamber delivers a high-current stream of energetic electrons into the ionization chamber; this electron stream is directed roughly parallel and adjacent to an extended slot in the front of the chamber. Ions are extracted from this slot by an ion extraction electrode, forming an energetic ion beam. During transport of the sublimated boron hydride vapor to the ionization chamber all surfaces are held at a higher temperature than that of the vaporizer (but well below the temperature of dissociation), to prevent condensation of the vapor. Over many hours of testing, we have confirmed that the surfaces of the vapor feed and valves indeed remain clean.

Sourc _ Lifetime Testing with Decaborane

The novel ion source was run continuously with decaborane feed material. The

source was run under controlled conditions at a given vapor flow, until it was determined that the buildup of material was causing a significant decrease in decaborane beam current. Five different flow rates were tested, ranging from about 0.40 sccm to 1.2 sccm. This resulted in mass-analyzed decaborane beam currents ($B_{10}H_x^+$) ranging from about 150 μA to 700 μA. We also note that typical process gas flows in the ion sources used in ion implantation range from 1 to about 3 sccm, so this test range is considered a "low" flow regime. An important discovery we found during these tests was that using an argon co-gas helped a great deal in stabilizing the ion beam over the extended test, especially at lowest decaborane flows, *i.e.,* below about 0.6 sccm. This information is presented in Figs. 4a and 4b. We expect that other noble gases such as xenon would be likewise beneficial when used in conjunction with low vapor flows.

The results of these lifetime tests are summarized in Fig. 5. It suggests a simple model, a hyperbolic function. This is not unexpected; to wit, if one assumes zero vapor flow, than the source lifetime would, in principle, diverge; and if one assumes very high vapor flow, then source lifetime would decrease asymptotically to zero. Thus, the model can be expressed by:

(flow rate) × (flow duration) = constant.

Equation (3) simply states that lifetime (*i.e.,* flow duration) is inversely proportional to flow rate; the constant is the amount of deposited material. If (3) is accurate, then the fraction of deposited material is independent of the rate of flow of material, which is consistent with our model describing a fixed cross section for dissociation and subsequent deposition. These data show that, using our novel ion source with about 0.5 sccm decaborane vapor flow and about 2.5 sccm argon co-gas, dedicated decaborane operation can be sustained for more than 100 hours. While this is acceptable in many cases, in commercial semiconductor fabs, source lifetimes of well over 200 hours are desired. We thus developed a novel means to increase service life and performance by implementing an *in-situ* cleaning procedure.

In-situ Etch Cleaning

Certain processes in semiconductor manufacturing involve the vacuum deposition of films. During these processes, substrates are coated by a variety of techniques, for example, by chemical vapor deposition (CVD). Coatings build up not only on the

substrates but on chamber surfaces as well, and it is desirable to remove these coatings to reduce contamination when processing subsequent substrates. One means to accomplish this is by introducing an etch gas into the chamber, such as NF_3 or C_3F_8. If a plasma is then sustained in the chamber, reactive gases such as F and F_2 are produced, and these reactive gases chemically attack the deposited materials. If the by-products are released in the gas phase, they are pumped away, cleaning the chamber. Recently, an extension of the above method has been used by some workers in CVD, namely "downstream reactive gas etching", or "remote" plasma cleaning. This is a version of etch cleaning which does not require plasma generation within the process chamber; instead, reactive ions are generate by a remote plasma ion source and introduced "downstream" into the process chamber. This has the potential advantage of better control of the chemical cleaning process, for example, by introducing even small amounts of reactive gas into targeted areas within the process chamber.

We have developed a chemical cleaning process utilizing atomic F gas, which effectively cleans deposits from the ion source and from the ion extraction electrode. We note that in a preferred embodiment of our novel ion source, the ionization chamber and source block are fabricated of aluminum; it turns out that aluminum is a metal of choice if one routinely uses halogen etching processes. This is because once aluminum fluoride is created on the aluminum surface, it acts as a passivating layer, preventing further chemical attack by F. Therefore, our novel source technology is chemically compatible with the proposed halogen cleaning process.

One embodiment of our novel cleaning method uses the outlet of a downstream reactive gas source directly coupled to an inlet to our novel ion source. Such an embodiment is disclosed in Fig. 7a. There are several very important advantages to this method, which we will now explain. First of all, one might think it strange to use an external ion source to generate plasma by-products to introduce into a *second* ion source; why not just introduce the (*e.g.,* NF_3) gas directly into the second ion source and create the plasma by-products within the source directly? The reasons are not obvious: 1) In order to realize etch rates which far exceed decaborane deposition rates, and can therefore be performed during a small fraction of the uptime of the implanter,

the reactive gas must be introduced at very high flows (*e.g.,* on the order of 10^2—10^3 sccm) compared to typical ion implanter flow rates (recall that typical gas flows in commercial implanter ion sources are in the range of 1—3 sccm); this would raise the pressure within the ion source far beyond where it is designed to operate. 2) Sustaining a high-density NF_3 plasma within the ion implanter source would etch away sensitive components, such as tungsten filaments. This is because halogen gases etch refractory metals at a very high rate; also, this etch rate increases exponentially with temperature. For example, Rosner *et al.* propose a model for F etching of a tungsten substrate:

(3) Rate (microns/min) = $2.92 \times 10^{-14} T^{½} N_F e^{-3900/T}$,

Where N_F is the concentration of fluorine atoms per cm^3 and T is the substrate temperature in degrees Kelvin.

Since virtually all implanter ion sources incorporate hot filaments, and since the ion source chambers are also made of refractory metals such as Mo and W, or graphite (which is aggressively attacked by F), these ion sources would quickly fail, making the etch cleaning process unusable. In the proposed embodiment of Fig. 7a, and Fig. 7b, atomic fluorine enters the ionization chamber of the ion source at a flow rate of 100 sccm or more, and the total gas flow into the ionization chamber is 500 sccm or more. Under these conditions, the gas pressure within the ionization chamber would be 0.5 Torr or so, and the pressure within the vacuum source housing of the implanter a few tens of milliTorr. Therefore, we recommend closing the isolation valves between the source vacuum housing and the rest of the implanter vacuum system, isolating the source turbopump, and pumping the source housing with the vacuum system's high-capacity roughing pumps (*i.e.,* the pumps which normally back the turbopumps and evacuate the vacuum system down to "rough" vacuum).

A different embodiment of a related etch clean process, shown in Fig. 6c, utilizes a "dry etch" gas such as ClF_3. ClF_3 has found some limited application in cleaning thin film deposition chambers utilizing CVD or sputtering, where it has been observed that the ClF_3 molecule breaks up on contact with the deposited surfaces to be cleaned; thus, atomic fluorine is released without requiring the generation of a plasma. While handling of ClF_3 gas requires special equipment due to its highly reactive nature, it in principle

simplifies our proposed chemical cleaning process since in this embodiment an ancillary reactive gas plasma source is not required. Since toxic gases are routinely fed into the implanter ion source anyway, a separate gas distribution system incorporating ClF_3 could be added in a straightforward manner. As with the plasma-based downstream reactive gas source described above, this means of cleaning ion implantation sources has never, to our knowledge, been reported.

Thus, the advantages of implementing an *in-situ* chemical clean of the ion implanter source would be: 1) extending source life to hundreds, or possibly thousands, of hours before service is required; 2) reducing or eliminating cross-contamination brought about by a species change, for example, switching from decaborane ion implantation to arsenic or phosphorus ion implantation, and from arsenic or phosphorus ion implantation to decaborane ion implantation; and 3) sustaining peak ion source performance through the service life of the source.

For example, performing a 5 or 10 minute chemical clean every eight hours (*i.e.*, once every shift change) and between each species change would have a minimal impact on the uptime of the implanter, and would be acceptable to a modern semiconductor fab.

Endpoint Detection

It would be beneficial to provide endpoint detection during the cleaning process, so that quantitative information on the efficacy and required duration of the cleaning process may be generated, and the reproducibility of the chemical cleaning process may be assured. Fig. 7a shows a differentially-pumped quadrupole mass analyzer sampling the cleaning process. By monitoring the concentrations of cleaning gas products such as F, Cl, BF_3, PF_3, AsF_3, AlF_3, WF_6, for example, the cleaning process may be tuned and verified. Alternatively, optical means of monitoring the process may be utilized. Fig. 7b shows an FTIR spectrometer monitoring the gases resident in the source vacuum housing of the implanter, through a viewport. This non-invasive means to identify chemical species may be preferable to in-situ monitoring devices in certain cases. Alternatively, an extractive FTIR spectrometer may be coupled to the source vacuum housing for endpoint monitoring. A novel means to accomplish endpoint

detection consists of monitoring the temperature of the ionization chamber during cleaning. Since the chemical reaction is exothermic, energy is released during the reaction, elevating the chamber temperature. This could easily be used to establish when the reaction rate is diminished.

Novel Ion Extraction Electrode

Boron hydrides such as decaborane and octadecaborane are thermally sensitive materials. They vaporize and condense at temperatures between 20C and 100C. It is therefore important to maintain all surfaces these materials come into contact with at a temperature higher than the vaporizer temperature, to prevent condensation. We have observed that contamination of the extraction electrode is a problem when using these materials. Both direct ion beam strike and condensed vapor can degrade operation of the ion beam formation optics, since these boron-containing layers appear to be electrically insulating. Once electrically insulating layers are deposited, they charge up and create vacuum discharges, or "glitches", upon breakdown. This creates instabilities in the ion beam current and can contribute to the creation of particles. An ion implanter which experiences many glitches per hour is not considered production-worthy in modern semiconductor fabs. As insulating coatings become thicker, the charged electrode surfaces create unwanted stray fields which can result in beam steering effects, creating beam loss.

We sought to better understand the high glitch rate phenomenon when using boron hydrides, and discovered new information which fortunately led us to a robust solution to this problem. Most implanter ion extraction electrodes are made of graphite. Graphite has many advantages in this application, including a low materials cost, ease of machining, high electrical conductivity, low coefficient of thermal expansion, and good mechanical stability at high temperatures. Initially, we used a graphite electrode also. When we observed beam instabilities after running boron hydrides, we suspected that the surfaces of the electrode had become insulating. We then collected samples of the electrode deposits and had a chemical analysis performed by x-ray fluorescence spectroscopy. The study revealed a chemical stoichiometry consistent with a boron-carbon compound of the form B_2C. Since B_4C, or boron carbide, is a known intrinsic insulator, we suspected that the boron-carbon matrix was insulating, as indeed

subsequent electrical measurements of the electrode surfaces showed. In addition, it appeared that metal surfaces in the vicinity of the ion source, including the front plate (*i.e.,* the ion extraction aperture plate) of the ion source also had deposited insulating coatings after long use. Subsequent to these studies, we fabricated an electrode of aluminum, and also incorporated radiant heaters which were designed to keep the electrode plates, *i.e.,* the suppression and ground electrodes, at a well-controlled temperature (see Fig. 6d) sufficiently high to prevent condensation of decaborane and octadecaborane. In addition, the suppression electrode, which faces the ion source, was fabricated of a single machined piece of aluminum and had a smooth, featureless appearance. All fasteners were also removed to the backside of the plates. These measures reduced the number and severity of potential discharge points in the event that insulating coatings were formed, since the electric field stress at a "point", or sharp feature, is many times greater than at a smooth surface.

The novel electrode demonstrated excellent performance, and operated reliably for more than 100 hours (at least ten times as long as the graphite electrode) with very low glitch frequency. We attributed this great improvement to: *i)* Al construction (*i.e.,* metal versus graphite), *ii)* Active heating and temperature control of the electrode plates, and *iii)* smooth electrode surfaces. It was found that operating the electrode plates at 200C gave good results, significantly reducing the amount of deposited material. However, we believe a temperature in the range 150C to 250C would give good results as well. The temperature should, however, be kept below 350C, the dissociation temperature of decaborane.

The radiative design shown in Fig. 6d demonstrated very good temperature uniformity. However, it is likely that incorporating resistive heaters, particularly using an aluminum electrode, should also yield good uniformity. This latter embodiment is illustrated in Fig. 6e, and could result in a simpler design requiring less maintenance.

I believe that other metals would also work in this application, for example molybdenum. Molybdenum has the advantage of being refractory, so it can withstand very high temperatures. It also has good thermal conductivity. Aluminum, on the other hand, is a column III element like In and B, and therefore offers the advantage of being only a mild contaminant in silicon (it is a P-type dopant in silicon), while transition metals

such as silicon are very detrimental to carrier lifetimes. It is also not readily attacked by halogens, whereas transition metals such as molybdenum are. The primary disadvantage of aluminum, however, is that it is not a high temperature material, but should be used below about 400 C.

Description of the Drawings

Fig. 1: Ion implantation system

Fig. 2: Ion extraction electrode

Fig. 3a: Novel ion source

Fig. 3b: Detail of novel ion source

Fig. 4a: $B_{10}H_x^+$ current versus Ar co-gas flow

Fig. 4b: $B_{10}H_x^+$ current with/without Ar co-gas

Fig. 5: Lifetime versus decaborane vapor flow rate

Fig. 6a: Novel electrode optics

Fig. 6b: Octadecaborane beam profiles

Fig. 6c: Electrode manipulator

Fig. 6d: Heated electrode (radiative)

Fig. 6e: Heated electrode (resistive)

Fig. 7a: Remote NF_3 reactive gas source implementation

Fig. 7b: Alternative NF_3 downstream F source implementation

Fig. 7c: ClF_3 gas clean implementation

Fig. 8a: Etch rate of Si coupon

Fig. 8b: Uncleaned ion extraction aperture after running $B_{10}H_{14}$

Fig. 8c: Ion extraction aperture after 5 min *in-situ* F clean

Fig. 8d: Ion extraction aperture after 15 min *in-situ* F clean

Fig. 8e: Ionization chamber before and after F cleaning cycle

Detailed Description

Fig. 1 shows the basic elements of a commercial ion implanter, with the novel ion source installed. The ion source 10 is inserted into the source vacuum housing 209 of

the ion implanter. The ion extraction electrode 220 extracts and accelerates ions from the ion source 10 to form an ion beam 240. Ion beam 240 propagates entirely in vacuum; from the electrode 220 it is bent and dispersed by dipole analyzer magnet 230 into separate beamlets which differ by their charge-to-mass ratio. The ion beamlet of interest passes through mass resolving aperture 270 and into a final acceleration (or deceleration) stage 310 prior to intercepting one or more device wafers 312 on disk 314. The source vacuum housing can be isolated from the remainder of the implanter's vacuum system by closing isolation valve 210. For example, isolation valve 210 is closed prior to removing the ion source for service.

Fig. 2 shows a top view (looking down) of a prior art electrode electrode 220 facing the novel ion source 10. The ion source 10 is held at a positive potential V_A with respect to the ion extraction electrode 220, which is at local ground potential, *i.e.*, at the potential of the vacuum housing. The ion extraction electrode 220 is a simple diode; electrode plate 302 is the "ground" electrode and plate 302 the "suppression" electrode, typically held a few thousand volts below ground potential by suppression power supply V_S. The ionization chamber 44 and ion extraction aperture 80 of novel ion source 10 are shown facing extraction electrode 220. The three plates 80, 300, 302 contain rectangular slots or apertures through which ions 90 are extracted; Fig. 2 illustrates the slot profiles in the "short", or dispersive, direction.

Novel Ion Source and Vaporizer

Figure 3a is a diagram of novel ion source 10 and its various components. The details of its construction, as well as its preferred modes of operation, are disclosed in detail by Horsky *et al.*, International Application No. PCT/US03/20197, filed June 26, 2003: "An ion implantation device and a method of semiconductor manufacturing by the implantation of boron hydride cluster ions", and by Horsky, U.S. Patent Application No. 10/183,768, "Electron impact ion source", submitted June 26, 2002, both herein incorporated by reference. The ion source 10 is one embodiment of a novel electron impact ionization source. Figure 3a is a cross-sectional schematic diagram of the source construction which serves to clarify the functionality of the components which make up the ion source 10. The ion source 10 is made to interface to an evacuated vacuum chamber of an ion implanter by way of a mounting flange 36. Thus, the portion

of the ion source 10 to the right of flange 36, shown in Fig. 3a, is at high vacuum (pressure $<1\times10^{-4}$ Torr). Gaseous material is introduced into ionization chamber 44 in which the gas molecules are ionized by electron impact from electron beam 70A or 70B, which enters the ionization chamber 44 through electron entrance aperture 71B such that electron beam 70A or 70B is aligned with ion extraction aperture 81, and exits ionization chamber 44 through electron exit aperture 71A. In one embodiment incorporating a single electron gun and a beam dump, shown in Fig. 3b, after leaving ionization chamber 44 the electron beam 70 is stopped by beam dump 72 located external to ionization chamber 44. Thus, ions are created adjacent to the ion extraction aperture 81, which appears as a slot in the ion extraction aperture plate 80. The ions are then extracted and formed into an energetic ion beam by an extraction electrode (not shown) located in front of the ion extraction aperture plate 80. Referring now to Fig. 3a, gases such as argon may be fed into the ionization chamber 44 via a gas conduit 33. Solid feed materials such as decaborane and octadecaborane can be vaporized in vaporizer 28, and the vapor fed into the ionization chamber 44 through vapor conduit 32 within the source block 35. Typically, ionization chamber 44, ion extraction aperture 80, source block 35 (including vapor feed 32), and vaporizer housing 30 are all fabricated of aluminum. Solid feed material 29, located under a perforated separation barrier 34a, is held at a uniform temperature by closed-loop temperature control of the vaporizer housing 30. Sublimated vapor 50 which accumulates in a ballast volume 31 feeds through conduit 39 and through throttling valve 100 and shutoff valve 110. The nominal pressure of vapor 50 between throttling valve 100 and shutoff valve 110 is monitored by capacitance manometer gauge 60. The vapor 50 feeds into the ionization chamber 44 through a vapor conduit 32, located in the source block 35. Thus, both gaseous and vaporized materials may be ionized by this ion source.

The flow of vapor to ionization chamber 44 is determined by the vapor pressure in the region just before vapor feed 32, *i.e.,* within shutoff valve 110. This is measured by a capacitance manometer pressure gauge 60 located between throttling valve 100 and shutoff valve 110. In general, the flow rate is proportional to the vapor pressure. This allows the pressure signal to represent flow, and to be used as a setpoint to select flow.

To generate a desired vapor flow into the ion source, vaporizer housing 30 is brought to a temperature such that when throttling valve 100 is in its fully open position, the desired flow rate is exceeded. Then the throttling valve 100 is adjusted to reach the desired pressure output. To establish a stable flow over time, separate closed-loop control of the vaporizer temperature and vapor pressure is implemented using dual PID controllers, such as the Omron E5CK digital controller. The control (feedback) variables are thermocouple output for temperature, and gauge output for pressure.

Source Operating Conditions for Decaborane

Fig. 4a shows how introducing argon gas into the ion source during decaborane operation affects the decaborane ion current delivered to the end of the implanter beamline, into its Faraday cup. The decaborane flow is low, only 0.48 sccm. Ion beam production increased by about 50% in this data set by the introduction of about 2.3 sccm of argon. The argon was introduced into the gas feed of the ionization chamber, while the decaborane was introduced through the vapor feed. No argon was introduced into the vaporizer itself. Fig. 4b shows the effect of introducing 2 sccm of argon into the ionization chamber over a broad range of decaborane flow rates. $B_{10}H_x^+$ beam current production is quite linear with vapor flow, both when argon is introduced and when only vapor is used. At the lowest vapor flows, beam current is higher when argon co-gas is used; at high vapor flows, less beam current is generated when argon is introduced. What is not represented in the data, however, is that the beam current is much more stable over long periods of time (hours or tens of hours) when argon is used at vapor flows below about 0.6 sccm.

Fig. 5 shows the results of source lifetime testing over a broad range of decaborane flows. Argon co-gas was used during these tests. The fit to these data is equation (3). No actual failures of the ion source were recorded during these tests; rather, the test was ended when the decaborane ion current dropped to roughly half of its initial level. Upon inspecting the ion source, it was found that a substantial amount of boron-containing material was deposited within the ionization chamber, mostly adhering to the interior walls of the chamber. In some cases, the ion extraction aperture was also

partially occluded. The model seems to fit the data well, and suggests that "lean" operation is the key to prolonged ion source lifetime, at least in the absence of chemical cleaning procedures.

During the decaborane lfetime tests displayed in Fig. 5, a novel heated aluminum electrode was used. Fig. 6a shows a top view of the basic optical design of the extraction system, in the dispersive plane of the one-dimensional "slot" aperture lenses. In our implanter, the ionization chamber 490 of the ion source is held at the desired ion beam energy by positive high voltage power supply V_A. For example, if a 20 keV ion beam is desired, then V_A = 20 kV. Ion extraction aperture 500 is electrically isolated from ionization chamber 490 such that it is bias able by bipolar power supply V_B from -750V—750V. The isolation is accomplished by a thermally conductive, electrically insulating polymeric gasket which is sandwiched between the ion extraction aperture 500 and ionization chamber 490. It is important to keep the parts of the ion source body exposed to vapor (source block 35, ionization chamber 44, and extraction aperture plate 80) in good thermal contact with each other to maintain controlled temperature surfaces during source operation. Ions produced in ionization chamber 490 are extracted through ion extraction aperture 500 by extraction electrode 540 consisting of suppression electrode 510 and ground electrode 520, and propagate as a focused ion beam along the beam axis 530. Suppression electrode 510, biased to a few thousand volts negative by power supply V_S, serves to suppress secondary electrons which are generated upstream from the suppression electrode due to beam strike, preventing these energetic electrons from backstreaming into the positively-biased ion source. The ionization chamber 490, ion extraction aperture plate 500, suppression electrode 510, and ground electrode 520 are all fabricated of aluminum, and have smooth, carefully polished surfaces to minimize local electric fields.

An important effect of biasing ion extraction aperture plate 500 is to change the focal length of the ion optical system of Fig. 6a. A negative bias increases the focal length, while a positive bias decreases the focal length. For large biases, the effect can be substantial. For diagnostic purposes, we have installed a scanning-wire profilometer

in our implanter, located at the entrance to the analyzer magnet, just downstream of the source housing isolation valve (see item 210 in Fig. 1). This scanner records the beam current distribution in the dispersive plane, and is useful to determine how well the ion beam is being focused in the dispersive plane. 20 keV octadecaborane beam profiles are shown in Fig. 6b for three different biasing conditions: -483V, 0, and +300V. The zero volt condition is substantially overfocused, the positive voltage condition more overfocused, and the negative voltage condition properly focused. The electrode position was held constant during the three measurements. As expected, the proper focusing condition yielded the highest currents at the implanter Faraday.

Novel Heated Electrode

Fig. 6c shows the novel electrode 600 mounted on a three-axis manipulator 610 which allows for motion (with respect to the ion source) in X, Z and Θ, as defined by coordinate system 620. Actiuator 613 controls X-motion, actuator 612 controls Z-motion, and actuator 611 controls Θ-motion. The manipulator 610 mounts to the side of the implanter vacuum housing via mounting flange 615.

Fig. 6d shows a partial exploded view of the radiatively-heated version of the novel electrode head. Shown are suppression electrode 700, ground electrode 710, heater plate 720, radiant heater wire 730. The suppression and ground electrodes are fabricated of aluminum, the heater plate of stainless steel, and the heater wire 730 of nichrome. We typically ran he electrode at 200C; once this temperature was reached, power consumption was about 60W to maintain this temperature. The heater power was controlled with a closed-loop PID controller, the Omron E5CK, based on readback of a thermocouple.

Fig. 6e shows a partial exploded view of a resistively-heated version of the novel electrode head. Shown are suppression electrode 800, ground electrode 810, and resistive heaters 820. The four resistive heaters 820 fit into sleeves 830, two into each electrode plate. The sleeves 830 are a split design such that the heater press-fits into the sleeve, achieving intimate contact. Intimate contact between heater and electrode

is important to insure proper heating of the electrode, and to prevent premature burnout of the heaters. Again, the Omron E5CK or equivalent can control the electrode temperature based on readbck of a thermocouple.

Chemical Cleaning System

Fig. 7a shows a preferred embodiment of a system to conduct *in-situ* chemical cleaning of the ion source and electrode. A remote plasma source 850 breaks up NF_3 feed gas into NF_3 products such as F, F_2, and N-containing compounds. These are fed into the novel ion source 10 from the outlet 860 of the remote plasma source 850 by a dedicated inlet 880. The remote plasma source 850 is mounted on the ground side of source bushing 890, and since the novel ion source runs at high voltage, a ceramic HV break 870 in vacuum isolates the remote plasma source. There are three feeds into the ionization chamber of the ion source 10: the cleaning gas inlet 880, the vapor feed 32, and the process gas feed 33, which is shown in Fig. 7a as an argon feed. A differentially-pumped residual gas analyzer (RGA) 895 senses the gases in the source vacuum housing 209 to look for reaction products of the chemical cleaning process, to accomplish endpoint detection. For example, in cleaning boron deposits, BF_3 gas should be present at a reduced level at the end of the process.

Fig. 7b shows an alternative embodiment of the innovative *in-situ* chemical cleaning system. The principal difference in Fig. 7b is that the remote plasma source is mounted on the HV side of the source bushing, and feeds reactive gas through reactive gas feed 900. The embodiment of Fig. 7b is actually the embodiment we used to generate all of the cleaning process data presented in Figs. 8a–8e. An advantage of the embodiment of Fig. 7a is that the facilities needed to support the remote plasma source, such as cooling water and electrical power, are at ground potential; the embodiment of Fig. 7b allows the remote plasma source to share the controls points of the ion source, and also allows the cleaning feed gas and argon purge gas to be supplied from the ion source gas distribution box, which is at source potential. Another, different, advantage of the embodiment of Fig. 7a is that a high-conductance line-of-sight path is established between the cleaning gas outlet 860 and ionization chamber

44; this allows the highest etch rate of deposited material. Comparison of line-of-sight and non line-of-sight etch rates is shown in Fig. 8a for silicon by F.

Fig. 7c shows an alternative embodiment of the innovative *in-situ* chemical cleaning system, wherein a remote plasma source is not used. Instead, the highly reactive gas ClF_3 is fed directly into ionization chamber 44 via reactive gas inlet 900. ClF_3 has been shown to be an effective chemical cleaning agent in CVD reactors. It is, however, not in widespread use since it requires advanced handling techniques such as specially passivated, double-walled gas distribution hardware. It is also very dangerous if released, being pyrophoric. Nevertheless, use of ClF_3 gas would obviate the need for a remote plasma source, simplifying the hardware required for cleaning.

We used the system of Fig. 7b to test the F cleaning process on 1-mm-thick silicon coupons staged inside of the ionization chamber 44, with the following modification: rather than incorporating a dedicated reactive feed 900, we used the vapor feed 32. This required removing the vaporizer between cleaning cycles. Two coupon locations were tested: one having line-of-sight with the reactive gas inlet (*i.e.*, the vapor feed 32), and one not having line-of-sight. The etch rates are shown in Fig. 8a as a function of NF_3 flow rate. During this process, a flow of 700 sccm of argon flow was maintained into the remote plasma source while the NF_3 flow rate was varied from 50 sccm to 500 sccm. The line-of-sight geometry shows a factor of about five increase in etch rate, and is therefore a preferred geometry if it can be done uniformly. To this end, the geometry portrayed in Fig. 7a should provide better etch uniformity and higher etch rates than that of Fig. 7b.

Fig 8b-8e shows how the cleaning process affects boron deposits within the ionization chamber and on the interior of the ion extraction aperture of the novel ion source. The observed etch rates had charactistics similar to the plot of Fig. 8a, but were a factor of 3 lower. Thus, for a NF_3 flow rate of 500 sccm, the etch rate for decaborane deposits were 7 μm/min (no line-of-sight), and 36 μm/min (line-of-sight). Fig. 8b shows the interior of the ion extraction aperture after running 4 hrs of decaborane at 0.8 sccm vapor flow (about 133 μm thick boron deposit) prior to cleaning,

Fig. 8c shows the same aperture plate after a 5 min F clean, and Fig. 8d shows the aperture plate after a 15 min F clean. The left side of the aperture plate is line-of-sight with the vapor feed, therefore the cleaning indicated in Fig. 8c is non-uniform; one can even observe from the cleaning patern that the vapor feed aperture is centered in the vertical direction! After 15 minutes (see Fig. 8d), the plate is almost completely free of deposits. Also, the ion extraction electrode was removed and inspected after long operation, and it was very clean with no observable decaborane deposits.

Fig. 8e shows before and after pictures of the ionization chamber. Again, a 15 min etch clean leaves the chamber nearly free of deposits. Since collecting these data, we conducted a test where we repeatedly cycled two hours of decaborane (>500μA of analyzed beam current) followed by a 15 min chemical clean, to see if the chemical cleaning process was injurious to the ion source or extraction electrode in any way. After 21 cycles there was no measureable change in the operating characteristics of the ion source or the electrode. We believe this shows that this F cleaning process promises to enable very long lifetime in ion source operation of condensable species.

Claims

1. A method of operating an ion source in an ion implanter in which a vaporized gas is fed into the ion source via a vapor feed conduit, and an inert gas is fed into the ion source in a separate gas feed at a higher flow rate than the vapor, the two gases being fed into the ion source simultaneously and continuously during ion beam generation.
2. The method of Claim 1 in which the vaporized gas is decaborane, $B_{10}H_{14}$.
3. The method of Claim 1 in which the vaporized gas is octadecaborane, $B_{18}H_{22}$.
4. The method of Claim 1 in which the vaporized gas is elemental arsenic, As.
5. The method of Claim 1 in which the vaporized gas is elemental phosphorus, P.
6. The method of Claim 1 in which the inert gas is argon, Ar.
7. The method of Claim 1 in which the inert gas is xenon, Xe.
8. The method of Claims 2 or 3 in which the vapor flow rate is maintained below 1.0 sccm.

9. The method of Claims 2 or 3 in which the vapor flow rate is maintained below 0.5 sccm.

10. A method of *in-situ* cleaning of an ion source in an ion implanter, in which reactive halogen gas is flowed into the ion source while the ion source is under vacuum.
11. The method of Claim 10 where the reactive halogen gas is fluorine, F.
12. The method of Claim 10 where the reactive halogen gas is chlorine, Cl.
13. The method of Claim 11 in which the flourine gas is introduced into the ion source from a remote plasma source.
14. The method of Claim 13 in which the fluorine gas is produced in the remote plasma source by an NF_3 plasma.
15. The method of Claim 13 in which the fluorine gas is produced in the remote plasma source by a C_3F_8 or CF_4 plasma.
16. The method of Claim 10 in which the reactive gas is ClF_3.
17. The method of Claim 10 in which the cleaning procedure is conducted to remove deposits after the ion source has run decaborane.
18. The method of Claim 10 in which the cleaning procedure is conducted to remove deposits after the ion source has run octadecaborane.
19. The method of Claim 10 in which the cleaning procedure is conducted to remove deposits after the ion source has run arsine, AsH_3.
20. The method of Claim 10 in which the cleaning procedure is conducted to remove deposits after the ion source has run phosphine, PH_3.
21. The method of Claim 10 in which the cleaning procedure is conducted between changing implant species.

22. An ion implantation system having an ion source and an electrode for extracting ions from said ion source, wherein said electrode is maintained at an elevated temperature, said temperature being sufficiently high to substantially reduce condensation of process gases and process gas products onto said electrode.
23. The system of Claim 22, wherein said electrode is fabricated of aluminum.

24. The system of Claim 22, wherein said electrode is fabricated of molybdenum.
25. The system of Claim 22, wherein said electrode is heated by radiative heaters.
26. The system of Claim 22, wherein said electrode is heated by resistive heaters.
27. The system of Claim 25 or Claim 26, wherein said electrode is controlled to a desired temperature.
28. The system of Claim 27, wherein said temperature is between 150C and 250C.
29. The system of Claim 23, wherein said electrode is periodically cleaned by exposure to reactive halogen-containing gas.

30. A method of *in-situ* cleaning of an ion extraction electrode in an ion implanter, in which reactive halogen gas is flowed onto the ion extraction electrode while it is under vacuum.
31. The method of Claim 30 where the reactive halogen gas is fluorine, F.
32. The method of Claim 30 where the reactive halogen gas is chlorine, Cl.
33. The method of Claim 31 in which the flourine gas is introduced into the vacuum housing of the implanter, wherein said extraction electrode resides, from a remote plasma source.
34. The method of Claim 33 in which the fluorine gas is produced in the remote plasma source by a NF_3 plasma.
35. The method of Claim 33 in which the fluorine gas is produced in the remote plasma source by a C_3F_8 plasma.
36. The method of Claim 30 in which the reactive gas is ClF_3.
37. The method of Claim 30 in which the cleaning procedure is conducted to remove deposits after the ion source has run decaborane.
38. The method of Claim 30 in which the cleaning procedure is conducted to remove deposits takes after the ion source has run octadecaborane.
39. The method of Claim 30 in which the cleaning procedure is conducted to remove deposits takes after the ion source has run arsine, AsH_3, or elemental arsenic, As.
40. The method of Claim 30 in which the cleaning procedure is conducted to remove deposits takes after the ion source has run phosphine, AsH_3, or

elemental phosphorus, P.

41. The method of Claim 30 in which the cleaning procedure is conducted between changing implant species.

42. An apparatus comprised of an ion source for generating dopant ions for semiconductor wafer processing, coupled to a remote plasma source which delivers F or Cl ions to the first ion source for the purpose of cleaning deposits in the first ion source.
43. The apparatus of Claim 42 wherein said ion source is temperature controlled to a given temperature.
44. The apparatus of Claim 42 wherein said ion source is used to generate boron-containing ion beams.
45. The apparatus of Claim 44 wherein said boron-containing ion beams are generated by feeding vaporized boron hydride material into said ion source.
46. The apparatus of Claim 45 wherein said boron hydride material is decaborane.
47. The apparatus of Claim 45 wherein said boron hydride material is octadecaborane.
48. The apparatus of Claim 42 wherein said ion source is used to generate arsenic-containing ion beams.
49. The apparatus of Claim 42 wherein said ion source is used to generate phosphorus-containing ion beams.
50. The apparatus of Claim 42 wherein the ionization chamber of said ion source is constructed of aluminum.

51. A vapor delivery system for delivering a steady flow of sublimated vapor to a chamber, comprised of a vaporizer, a mechanical throttling valve, and a pressure gauge.
52. The system of Claim 43 wherein the vapor flow rate is determined by both the temperature of the vaporizer and the conductance of the mechanical throttle valve located between the vaporizer and chamber.
53. The system of Claim 44 wherein the temperature of the vaporizer is determined

by closed-loop control to a setpoint temperature.

54. The system of Claims 44 wherein the mechanical throttle valve is electrically controlled.
55. The system of Claim 46 wherein the valve position is under closed-loop control to the output of the pressure gauge.
56. The system of Claim 47 wherein the vapor flow rate is proportional to the pressure gauge output.

57. An ion source having a front extraction aperture plate able to be biased to a voltage different than that of its ionization chamber, and intended to be part of an ion optical beam-forming system in an ion implanter.
58. The ion source of Claim 49 wherein the electrical isolation between extraction aperture plate and ionization chamber is accomplished by insertion of an electrically insulating, thermally conductive and flexible gasket between them.
59. The ion source of Claim 49 wherein the ion optical system consists of at least three apertured electrodes, namely an ion extraction aperture plate, a suppression electrode plate, and a ground electrode plate.
60. The ion source of Claim 51, the purpose of said ion optical system being to extract, accelerate and focus ions formed within the ion source.
61. The ion source of Claim 52 wherein biasing of said ion extraction aperture plate changes the focal length of said ion optical system, to accomplish improved focusing and transport of the ion beam.
62. The ion source of Claim 53 wherein said ion extraction aperture plate is continuously bias able between -750V and +750V with respect to its ionization chamber.

Abstract

Novel means to enhance and prolong ion source service lifetime in ion implantation are disclosed. In particular, techniques are described for *in-situ* etch cleaning of an ion source and an extraction electrode by reactive halogen gases. An apparatus comprised of an ion source for generating dopant ions for semiconductor wafer processing, coupled to a remote plasma source which delivers F or Cl ions to the first ion source for the purpose of cleaning deposits in the first ion source, is described. These methods and apparatus enable long equipment uptime when running condensable feed gases such as sublimated vapor sources, and are particularly applicable for use with so-called cold ion sources. Methods and apparatus are described which enable long equipment uptime when decaborane and octadecaborane are used as feed materials, as well as when vaporized elemental arsenic and phosphorus are used, and which serve to enhance beam stability during ion implantation.

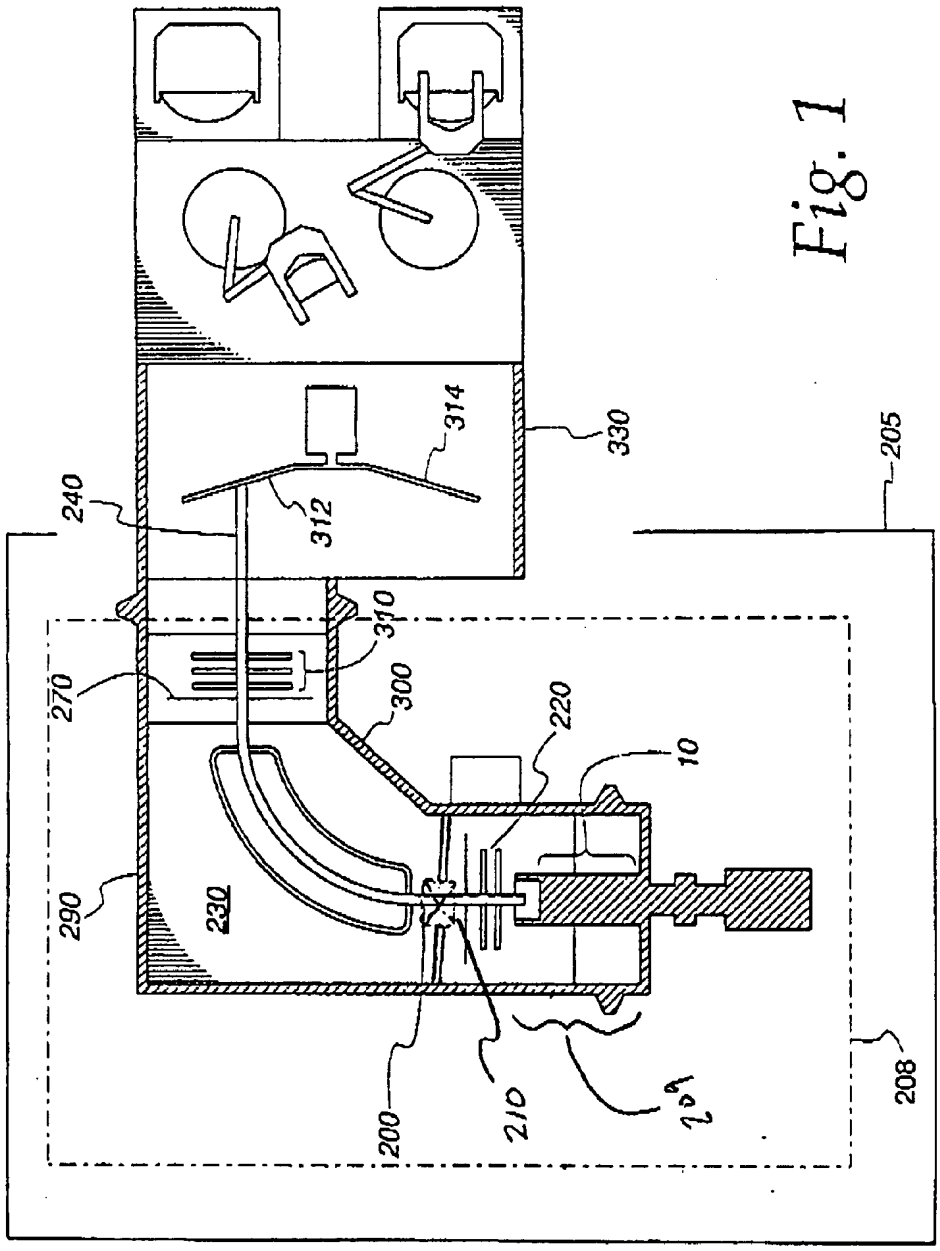
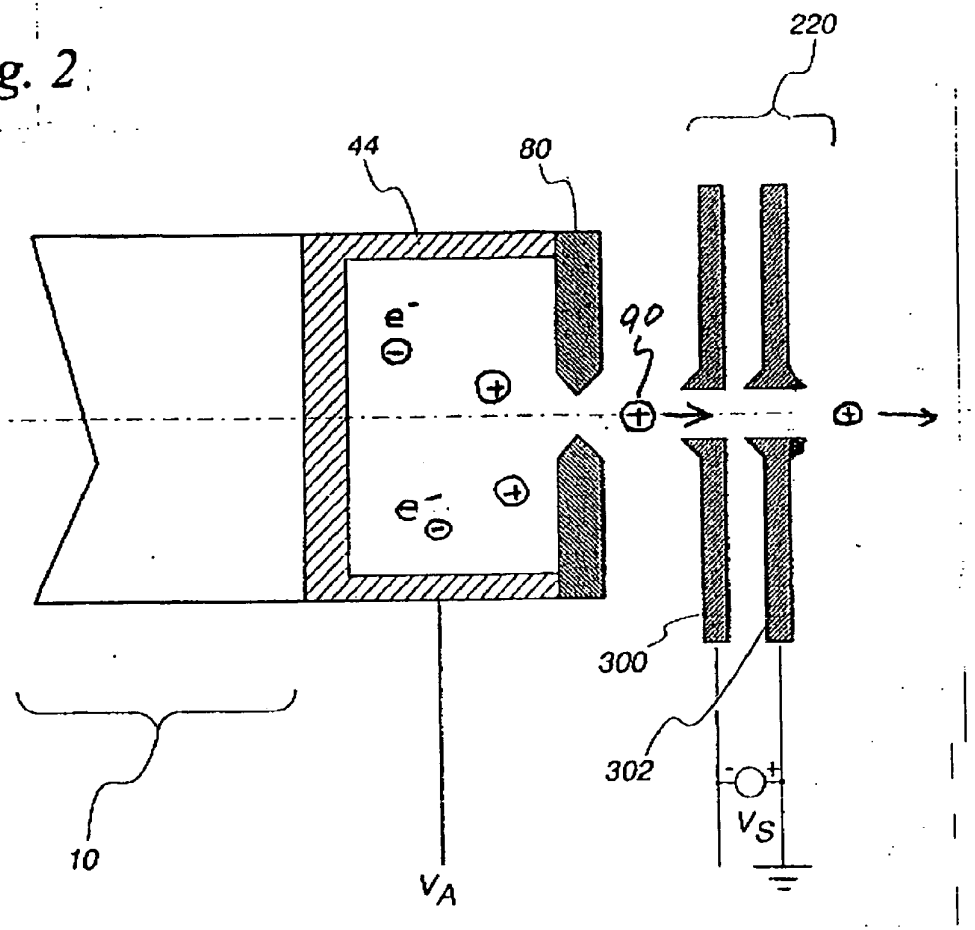
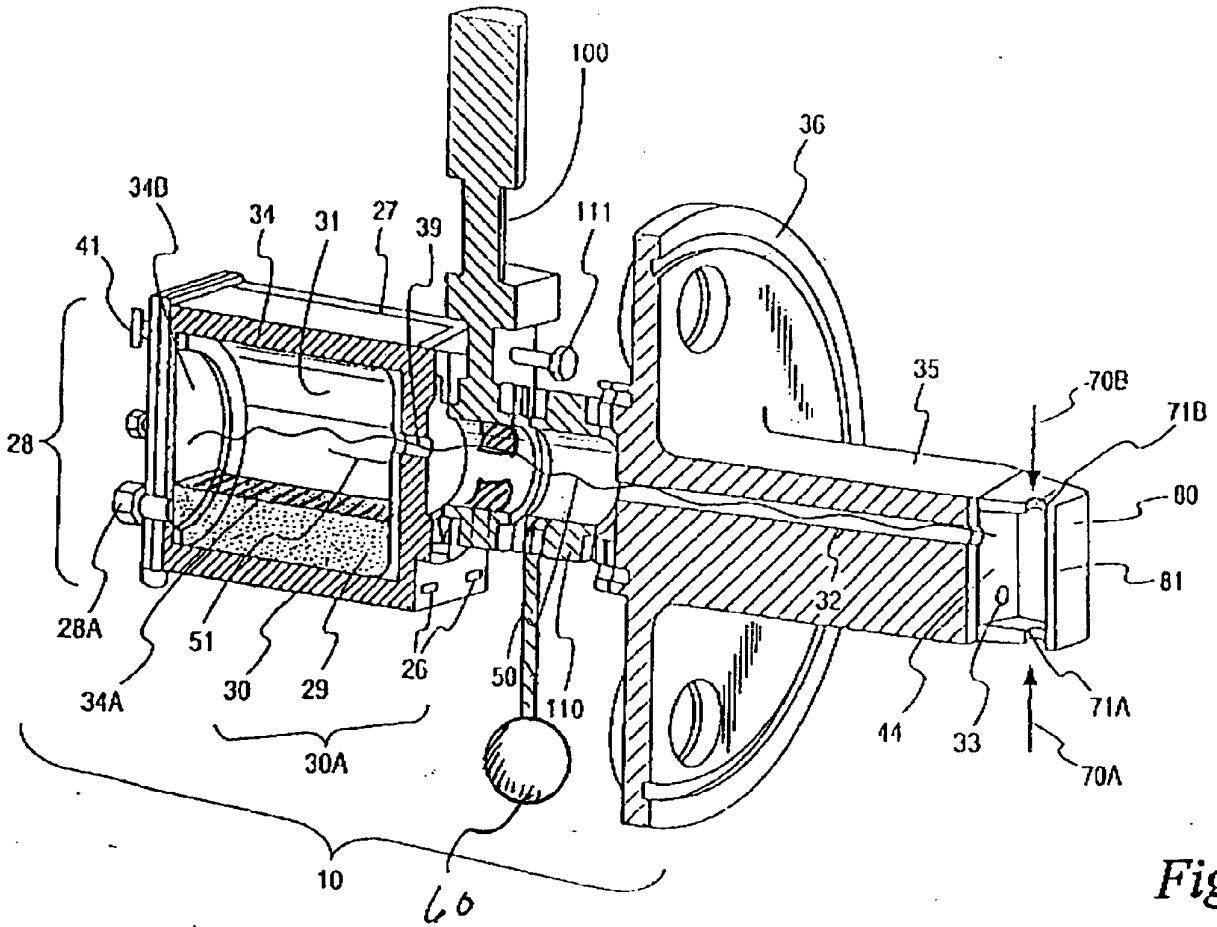


Fig. 1

Fig. 2

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31
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39
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71B
28
80
81
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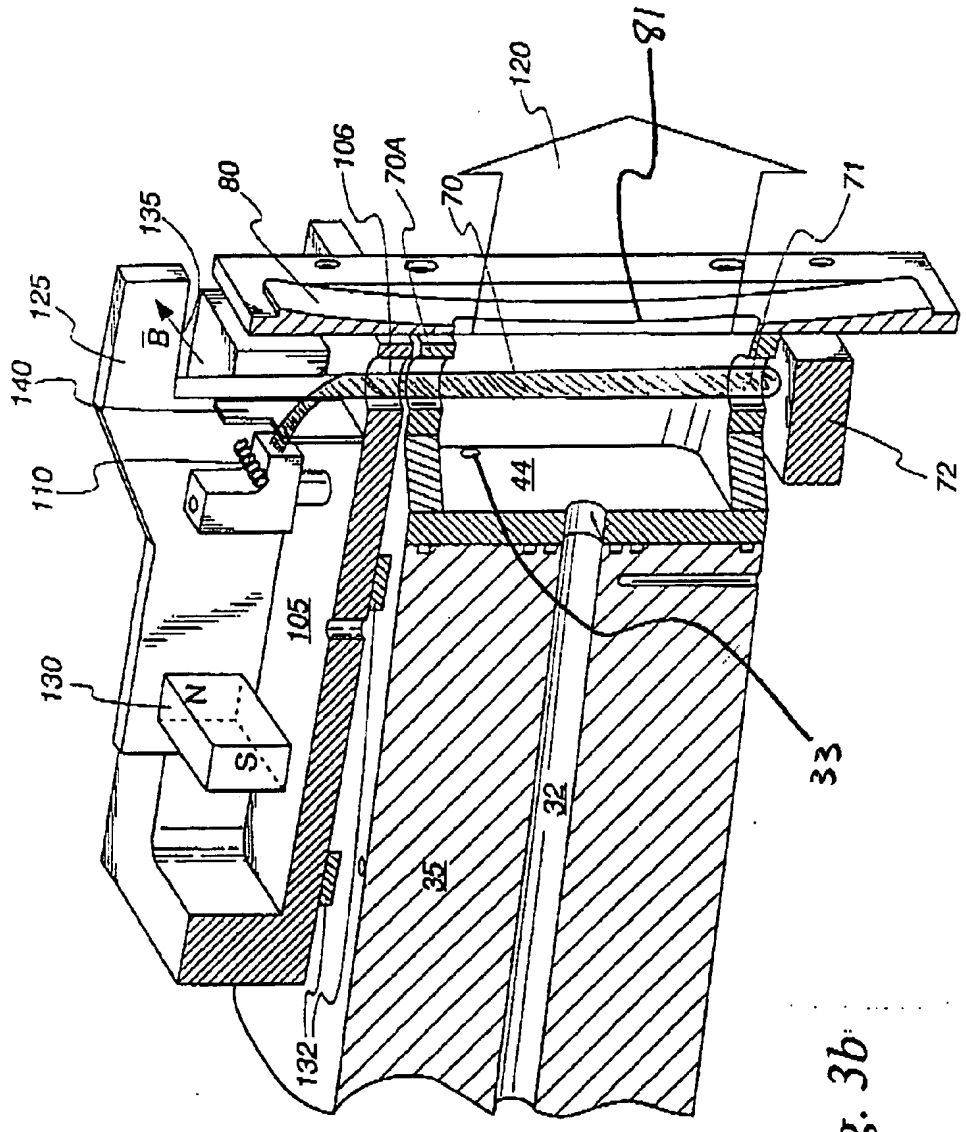
34A
30
29
26
50
110
71A
44
33
70A
30A
10
60

Fig. 3a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106
70A
70
80
135
71
125
B
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110
44
72
105
130
N
S
33
32
35
132

Fig. 3b

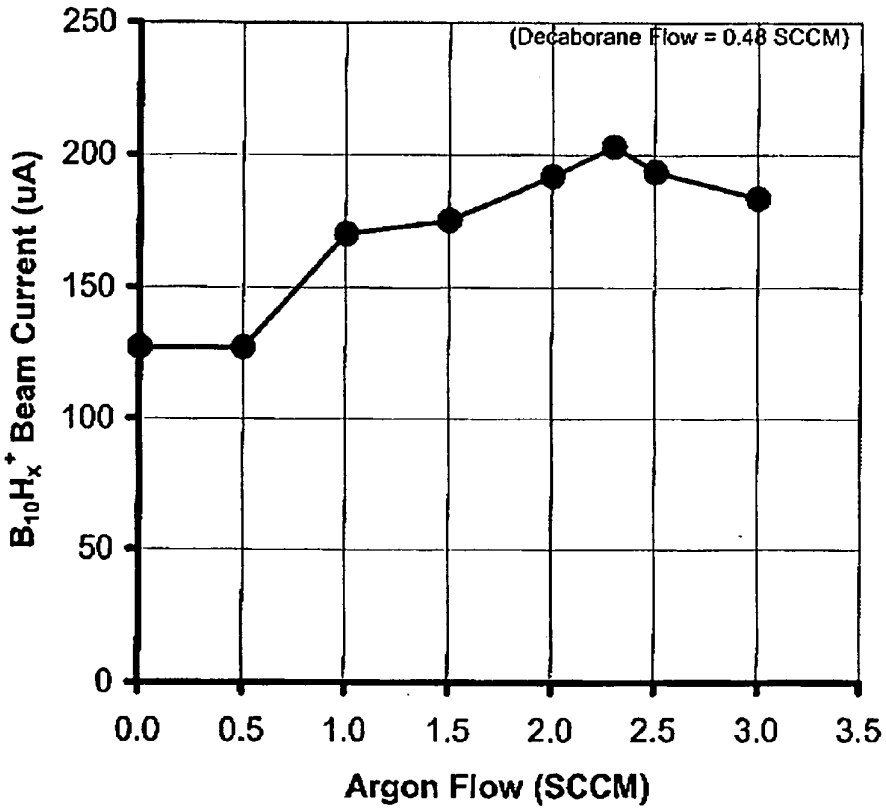
(Decaborane Flow = 0.48 SCCM)
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
$B_{10}H_x^+$ Beam Current (uA)
Argon Flow (SCCM)

Fig. 4a

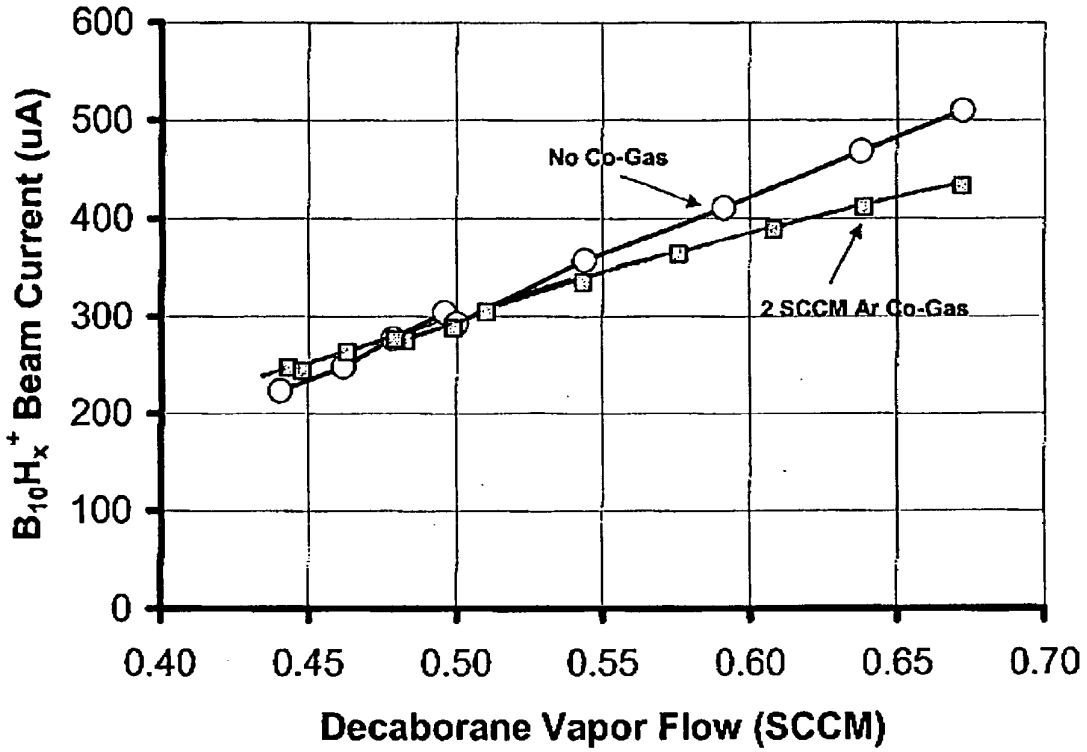
600
500
400
300
200
100
0
$B_{10}H_x^+$ Beam Current (uA)
No Co-Gas
2 SCCM Ar Co-Gas
0.40
0.45
0.50
0.55
0.60
0.65
0.70
Decaborane Vapor Flow (SCCM)

Fig. 4b

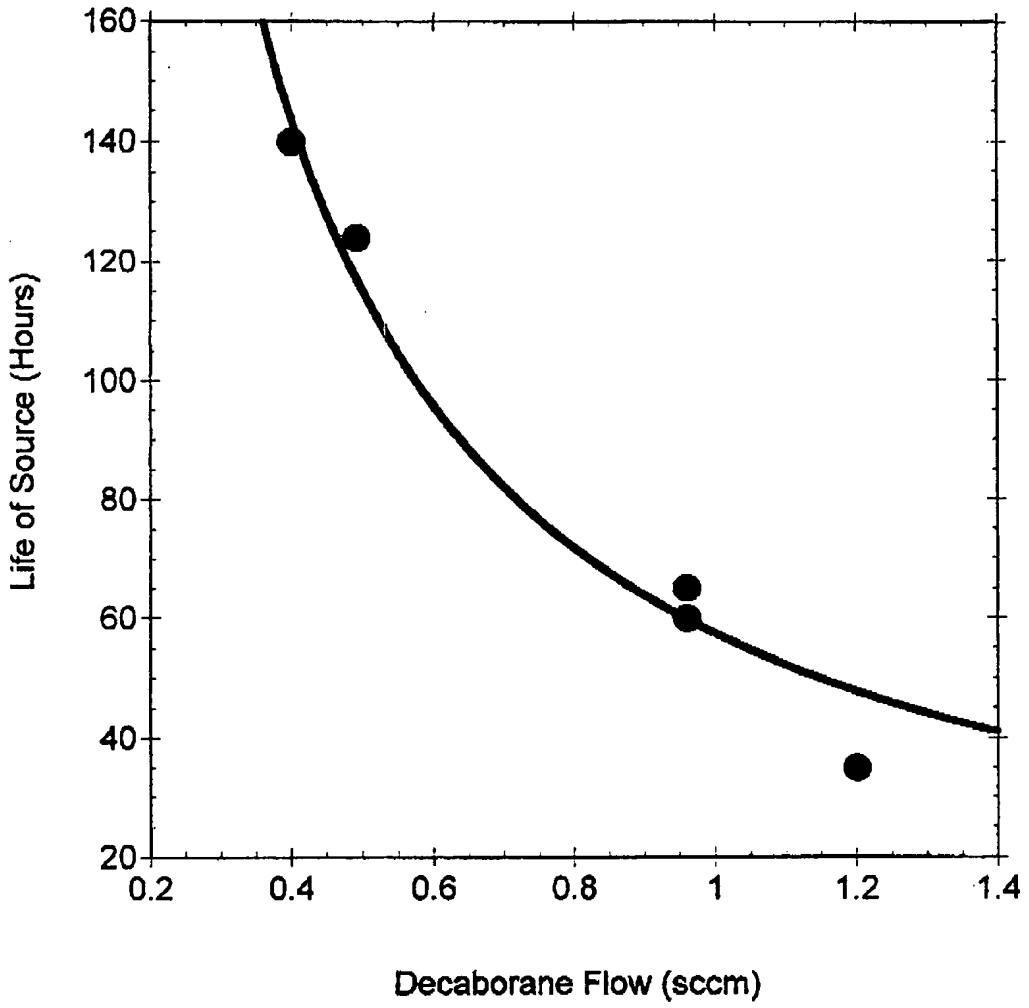
160
140
120
100
80
60
40
20
Life of Source (Hours)
0.2
0.4
0.6
0.8
1
1.2
1.4
Decaborane Flow (sccm)

Fig. 5

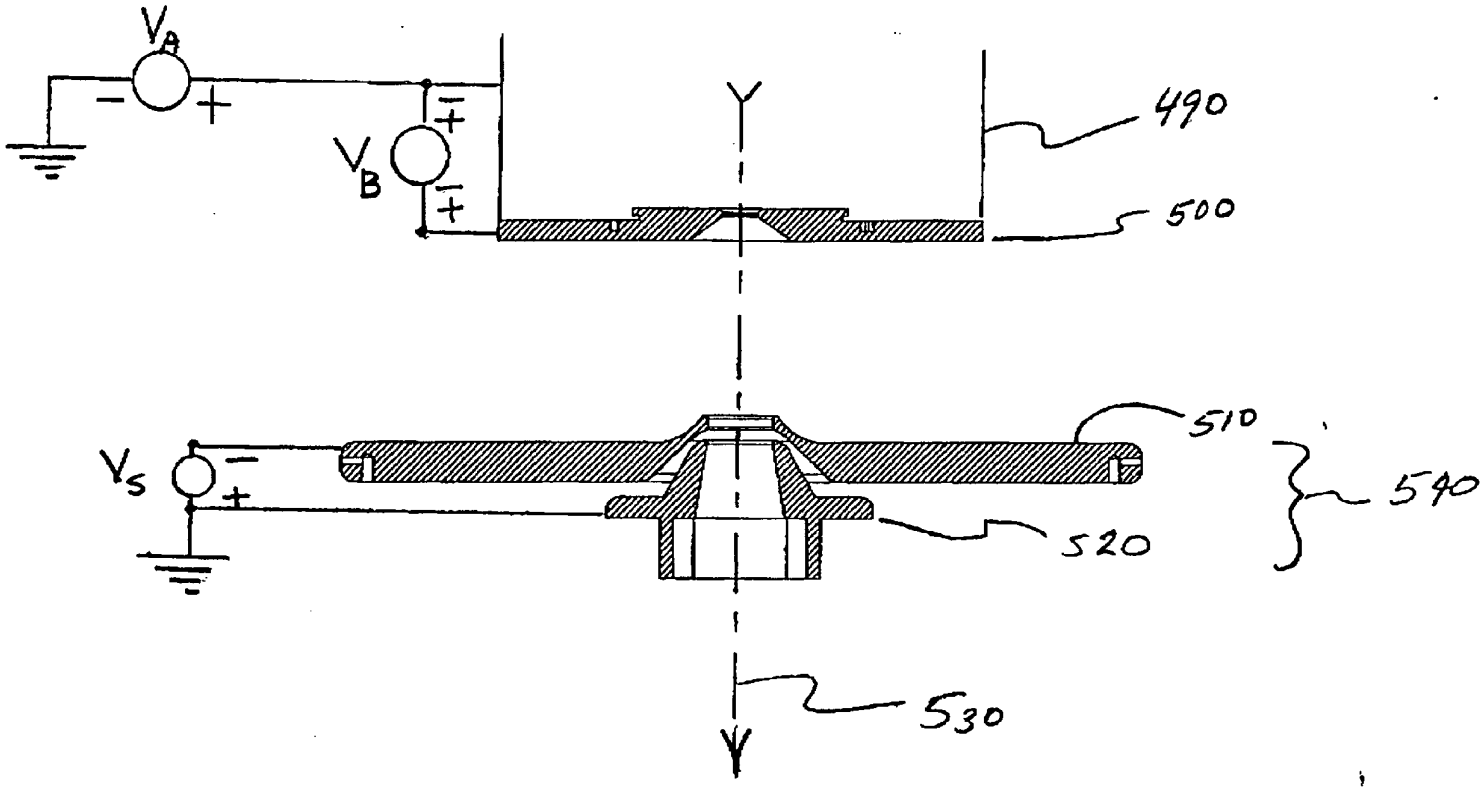

Fig. 6a

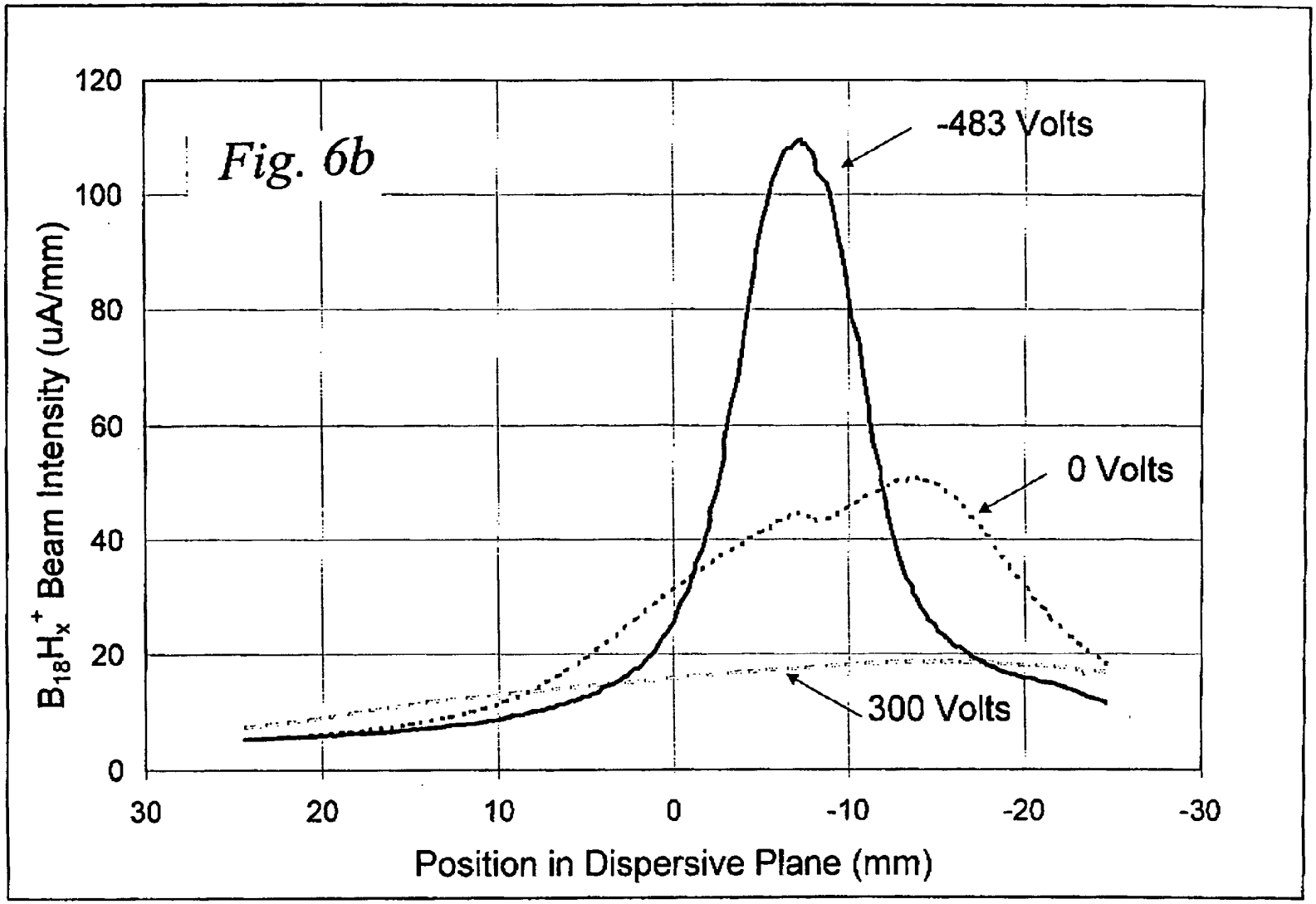
Fig. 6b
120
100
80
60
40
20
0
$B_{18}H_x^+$ Beam Intensity (uA/mm)
-483 Volts
0 Volts
300 Volts
30
20
10
0
-10
-20
-30
Position in Dispersive Plane (mm)

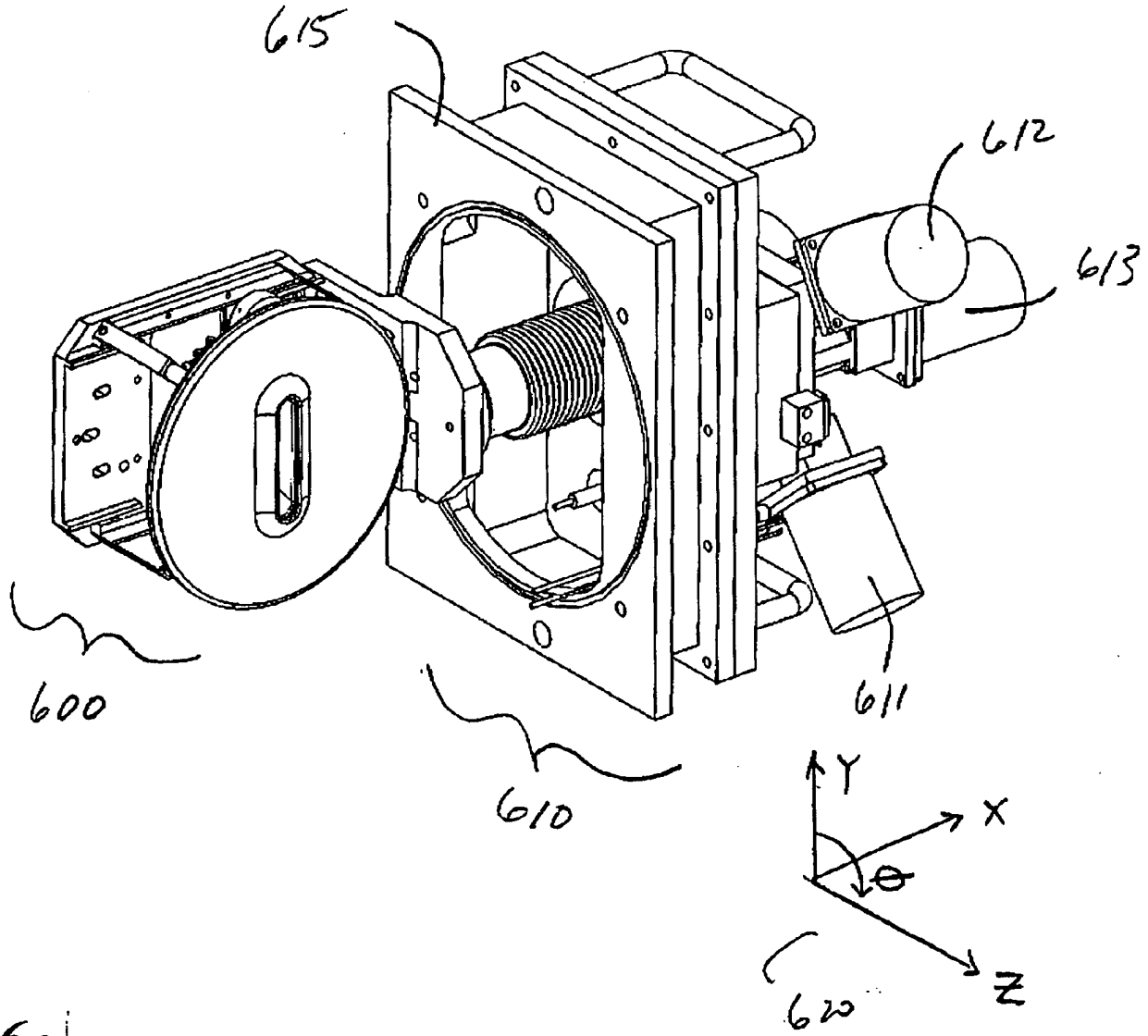

Fig. 6c

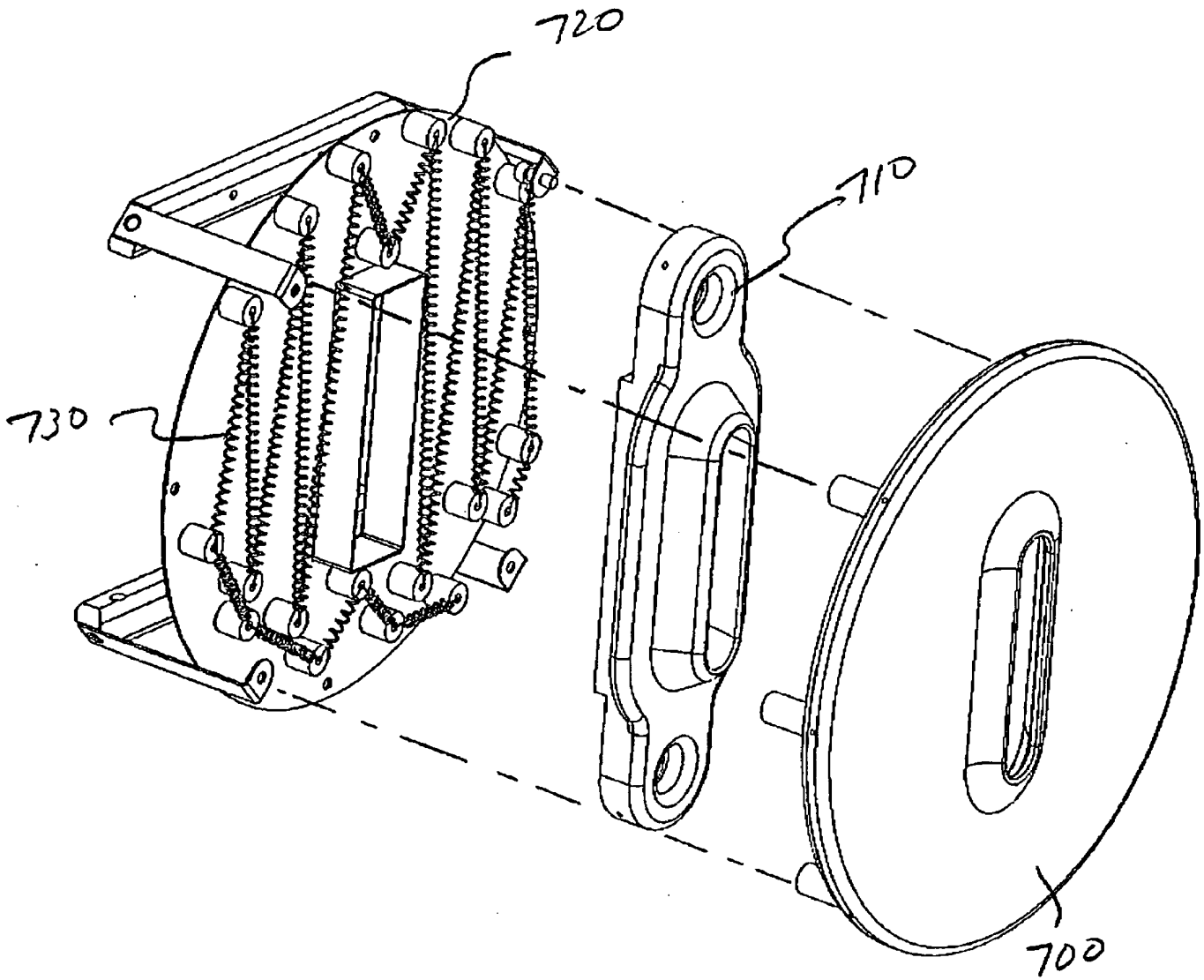

Fig. 6d

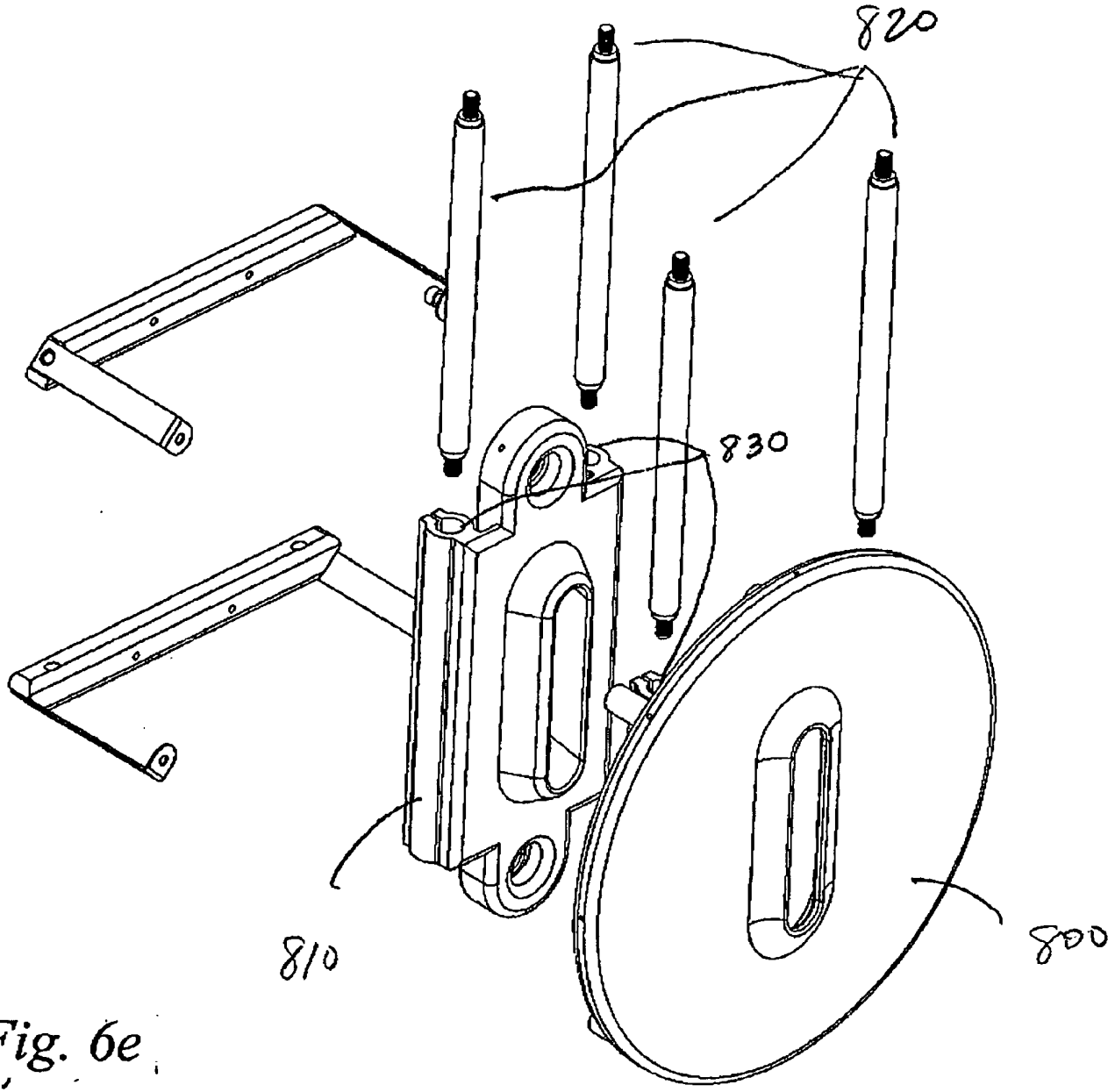

Fig. 6e

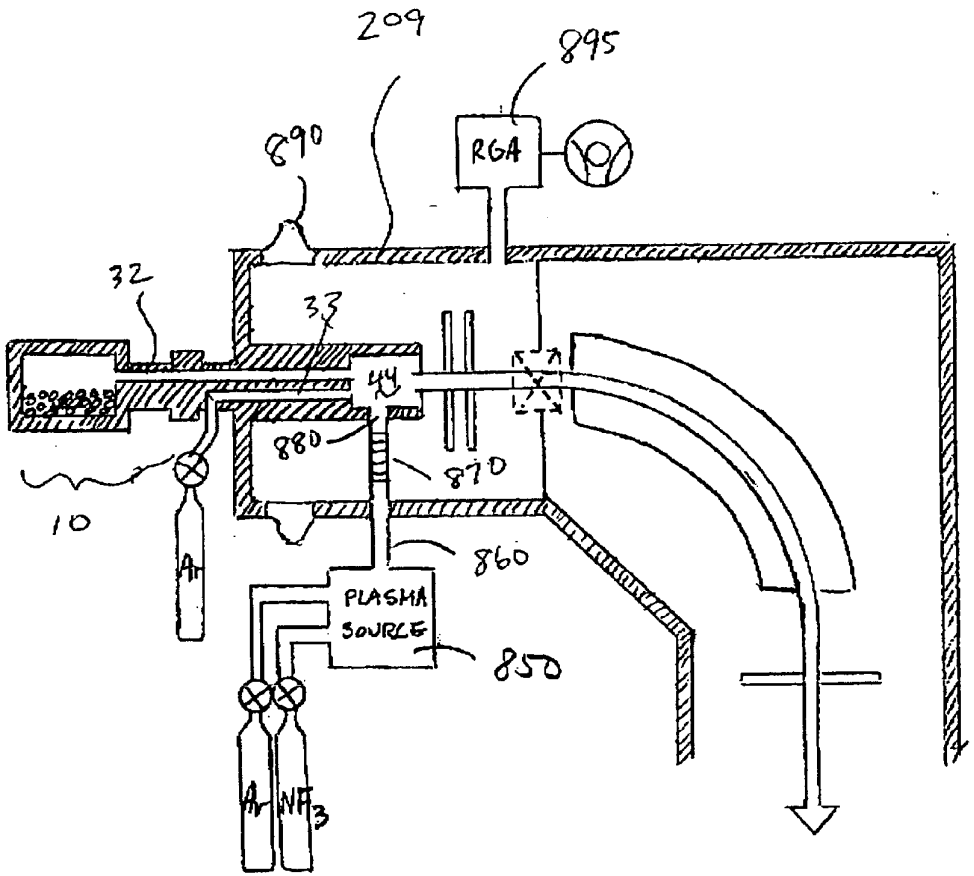

Fig. 7a

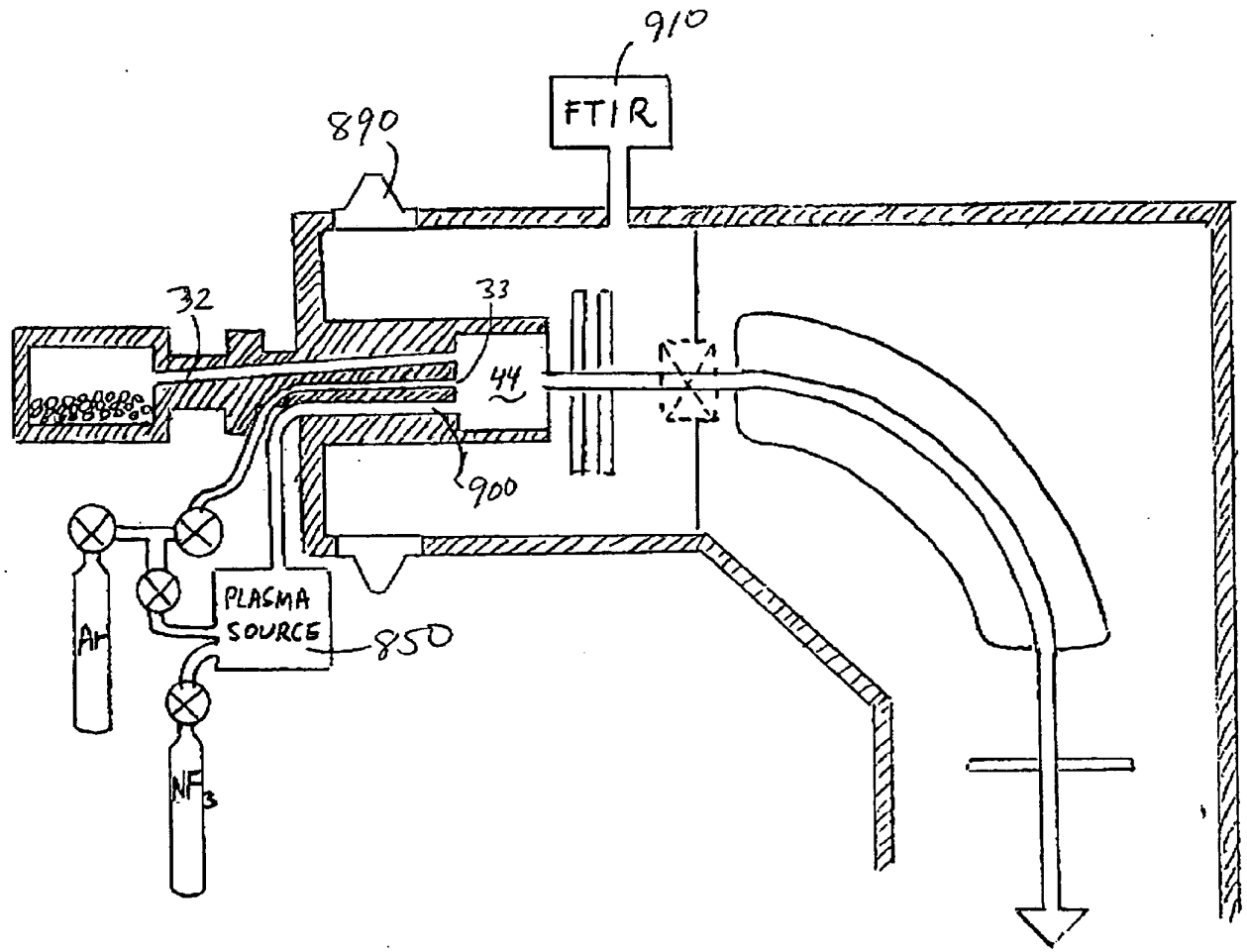

Fig. 7b

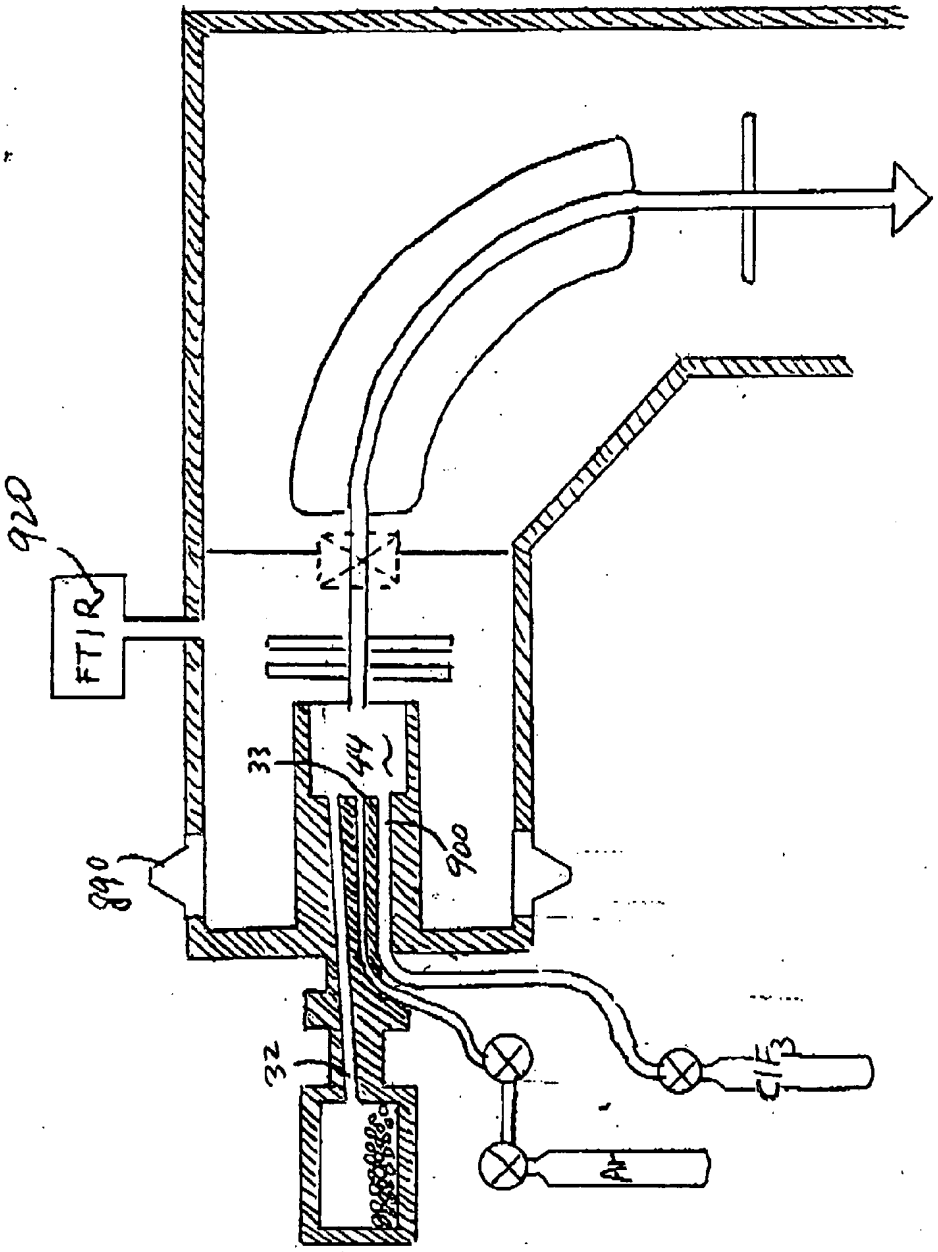

Fig. 7c

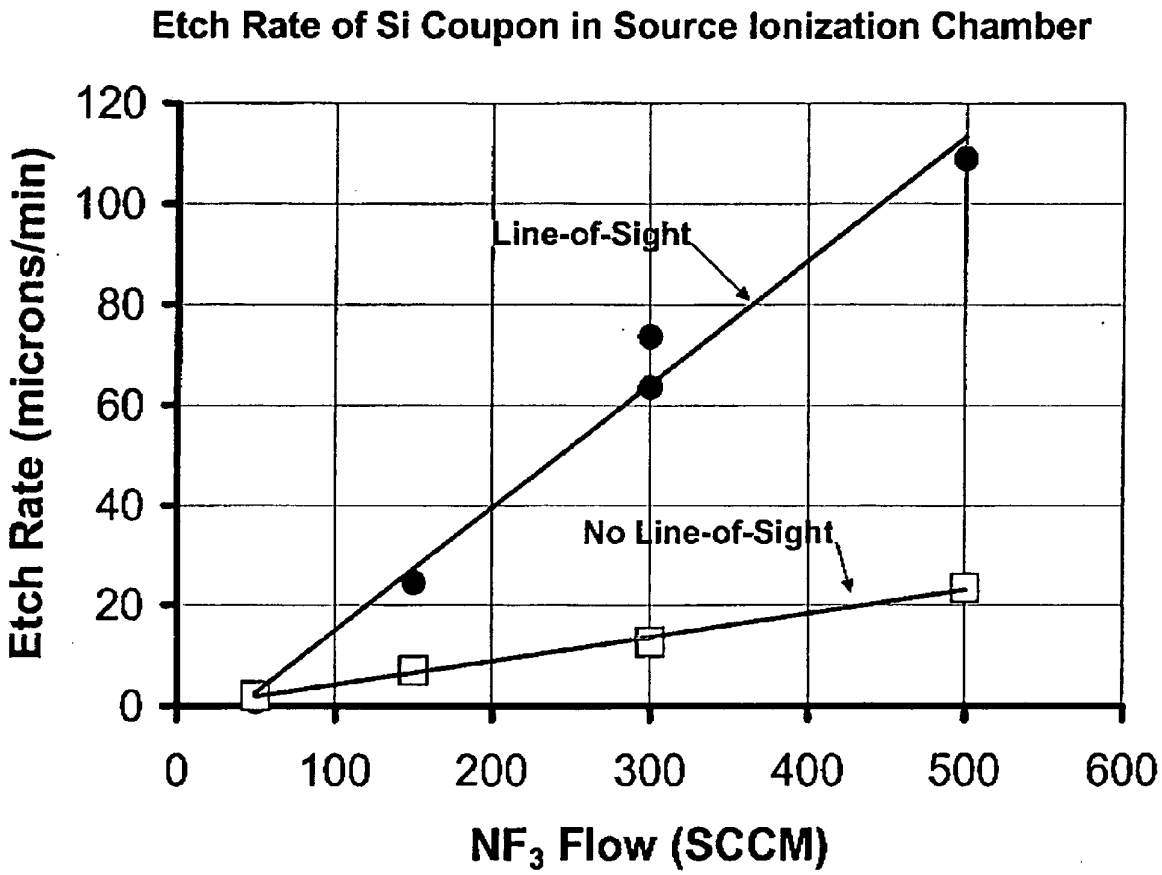
Etch Rate of Si Coupon in Source Ionization Chamber
Etch Rate (microns/min)
120
100
80
60
40
20
0
Line-of-Sight
No Line-of-Sight
0
100
200
300
400
500
600
NF3 Flow (SCCM)

Fig. 3a

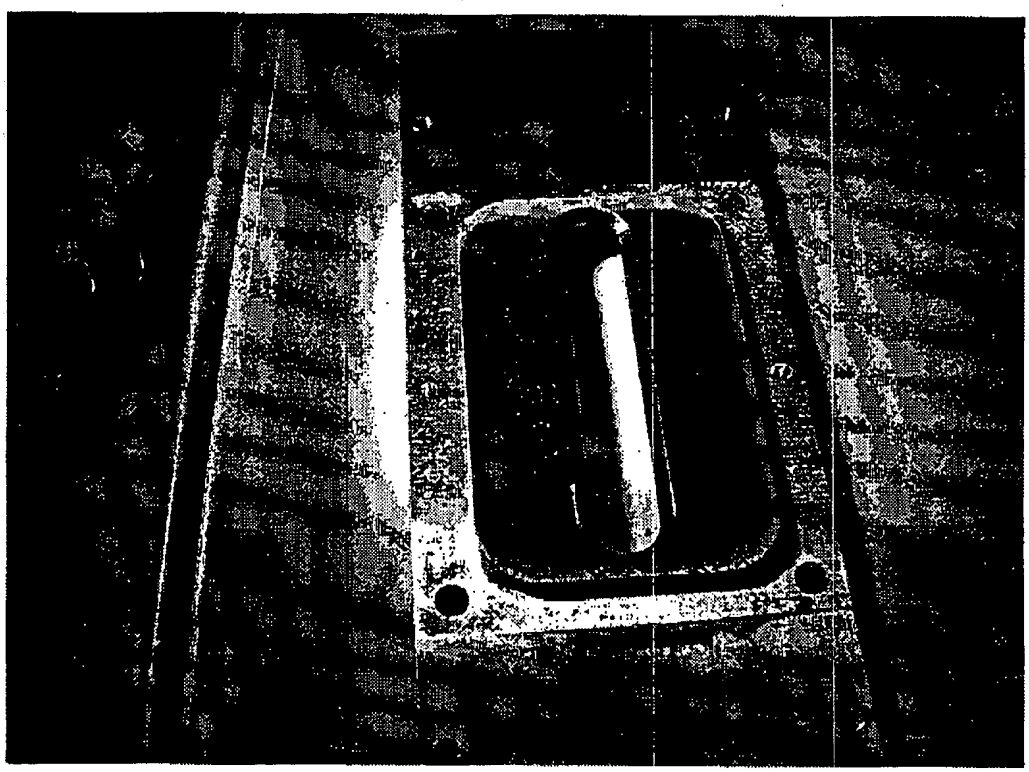

Fig. 8b

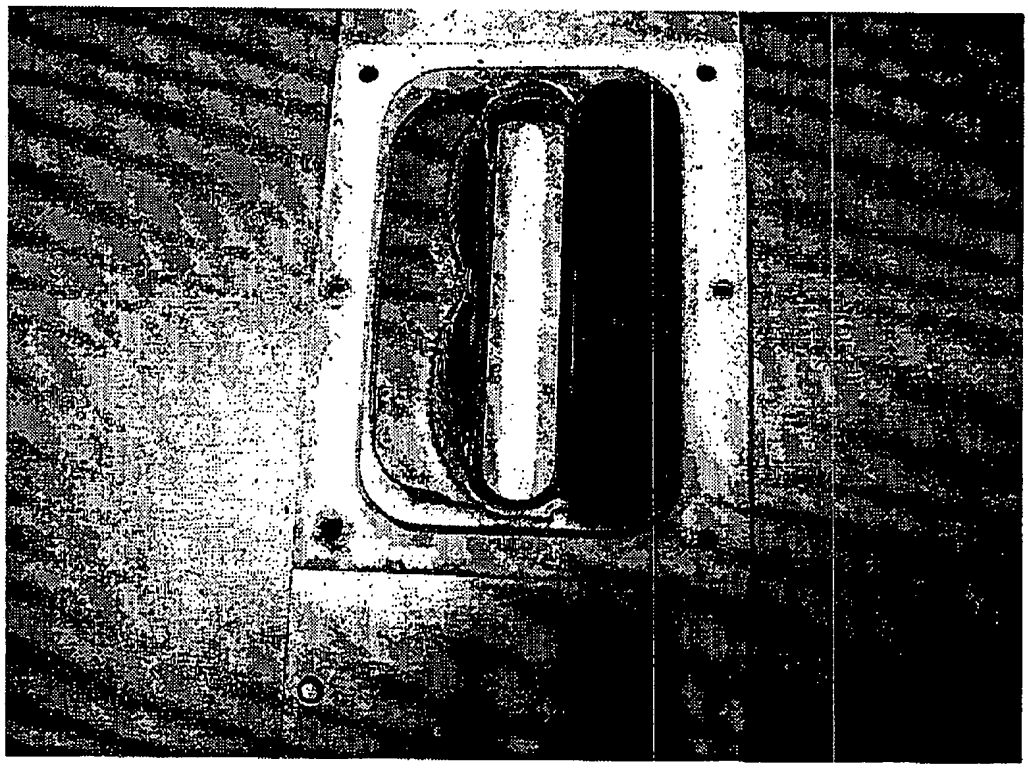

Fig. 8c

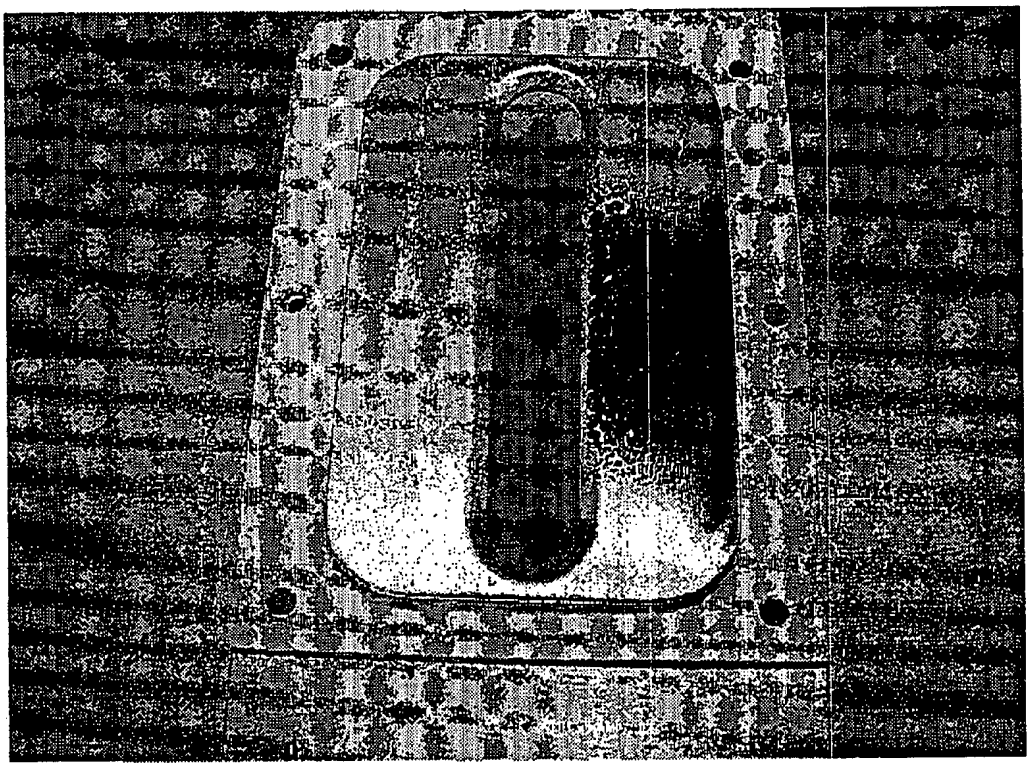

Fig. 8d

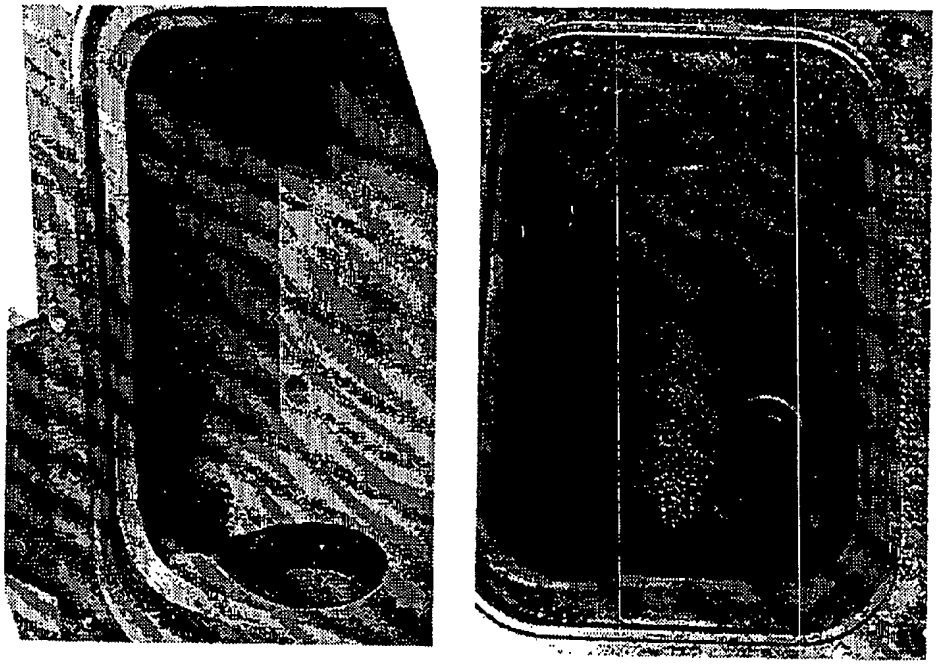

Fig. 8e

16152 U.S. PTO
60/529343
12/12/2003

PTO/SB/16 (08-0
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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EK580291658US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Thomas N. Dale C.	Horsky Jacobson	Boxborough, MA Salem, NH

Additional inventors are being named on the 1 *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

METHOD AND APPARATUS FOR EXTENDING EQUIPMENT UPTIME IN ION IMPLANTATION

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☑ Customer Number: 27160

OR

☐ Firm or Individual Name					
Address					
Address					
City		State		Zip	
Country		Telephone		Fax	

ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 28
☑ Drawing(s) *Number of Sheets* 20
☐ Application Data Sheet. See 37 CFR 1.76
☐ CD(s), Number
☐ Other (specify)

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.
☐ A check or money order is enclosed to cover the filing fees.
☑ The Director is herby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 50-1214
☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE Amount ($): 80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☑ No.
☐ Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

SIGNATURE

TYPED or PRINTED NAME John S. Paniaguas

TELEPHONE 312-902-5312

Date Dec. 12, 2003

REGISTRATION NO. 31,051 *(if appropriate)*

Docket Number: 211843-00033

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application formato the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: **Mail Stop Provisional Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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Additional Pag

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INVENTOR(S)/APPLICANT(S)

Given Name (first and middle [if any])	Family or Surname	Residence (City and either State or Foreign Country)
George P. Wade A.	Sacco Krull	Topsfield, MA Marblehead, MA
Robert S.	Milgate III	Gloucester, MA

Number 2 of 2

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PTO/SB/17 (10-03)
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FEE TRANSMITTAL for FY 2004

Effective 10/01/2003. Patent fees are subject to annual revision.

☒ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT ($) 80.00

Complete If Known	
Application Number	HEREWITH
Filing Date	HEREWITH
First Named Inventor	THOMAS J. HORSKY
Examiner Name	N/A
Art Unit	N/A
Attorney Docket No.	211843-00033

METHOD OF PAYMENT (check all that apply)

☐ Check ☐ Credit card ☐ Money Order ☐ Other ☐ None

☒ Deposit Account:

Deposit Account Number: 50-1214

Deposit Account Name: KMZ ROSENMAN

The Director is authorized to: (check all that apply)

☒ Charge fee(s) indicated below ☒ Credit any overpayments

☒ Charge any additional fee(s) or any underpayment of fee(s)

☐ Charge fee(s) indicated below, except for the filing fee to the above-identified deposit account.

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1001	770	2001	385	Utility filing fee	
1002	340	2002	170	Design filing fee	
1003	530	2003	265	Plant filing fee	
1004	770	2004	385	Reissue filing fee	
1005	160	2005	80	Provisional filing fee	80.00

SUBTOTAL (1) ($) 80.00

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

	Extra Claims		Fee from below	Fee Paid
Total Claims		-20** =		X	
Independent Claims		-3** =		X	
Multiple Dependent					

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
1202	18	2202	9	Claims in excess of 20
1201	88	2201	43	Independent claims in excess of 3
1203	290	2203	145	Multiple dependent claim, if not paid
1204	88	2204	43	** Reissue independent claims over original patent
1205	18	2205	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 0.00

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1051	130	2051	65	Surcharge - late filing fee or oath	
1052	50	2052	25	Surcharge - late provisional filing fee or cover sheet	
1053	130	1053	130	Non-English specification	
1812	2,520	1812	2,520	For filing a request for ex parte reexamination	
1804	920*	1804	920*	Requesting publication of SIR prior to Examiner action	
1805	1,840*	1805	1,840*	Requesting publication of SIR after Examiner action	
1251	110	2251	55	Extension for reply within first month	
1252	420	2252	210	Extension for reply within second month	
1253	950	2253	475	Extension for reply within third month	
1254	1,480	2254	740	Extension for reply within fourth month	
1255	2,010	2255	1,005	Extension for reply within fifth month	
1401	330	2401	165	Notice of Appeal	
1402	330	2402	165	Filing a brief in support of an appeal	
1403	290	2403	145	Request for oral hearing	
1451	1,510	1451	1,510	Petition to institute a public use proceeding	
1452	110	2452	55	Petition to revive - unavoidable	
1453	1,330	2453	665	Petition to revive - unintentional	
1501	1,330	2501	665	Utility issue fee (or reissue)	
1502	480	2502	240	Design issue fee	
1503	640	2503	320	Plant issue fee	
1460	130	1460	130	Petitions to the Commissioner	
1807	50	1807	50	Processing fee under 37 CFR 1.17(q)	
1806	180	1806	180	Submission of Information Disclosure Stmt	
8021	40	8021	40	Recording each patent assignment per property (times number of properties)	
1809	770	2809	385	Filing a submission after final rejection (37 CFR 1.129(a))	
1810	770	2810	385	For each additional invention to be examined (37 CFR 1.129(b))	
1801	770	2801	385	Request for Continued Examination (RCE)	
1802	900	1802	900	Request for expedited examination of a design application	

Other fee (specify) _____

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($) 0.00

SUBMITTED BY

(Complete if applicable)

Name (Print/Type)	JOHN S. SANTAGUAS	Registration No. (Attorney/Agent)	31,051
Telephone	312-902-5312		
Signature		Date	DEC 12 2003

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Attorney Docket No.: 211843-00033
Application No.: Herewith
First Inventor: Thomas N. Horsky
Title: METHOD AND APPARATUS FOR EXTENDING EQUIPMENT UPTIME IN ION IMPLANTATION

CERTIFICATE OF MAILING BY "EXPRESS MAIL"

"Express Mail" Mailing Label No.: EK560291658US

Date of Deposit: December 12, 2003

I hereby certify that the below-listed papers or fees are being deposited with the United States Postal Service "Express Mail Post Office to Addressee" Service under 37 CFR § 1.10 on the date indicated above and are addressed to the Mail Stop Provisional Patent Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

1. Return Receipt Postcard
2. Provisional Patent Application Cover Sheet including Certificate of Mailing by Express Mail (3 pages)
3. Fee Transmittal form (1 page – in duplicate)
4. Specification (28 pages, including claims and Abstract)
5. Informal Drawings (20 sheets)

Maria Arreola-Flores
(Typed or printed name of person mailing)

Maria Arreola-Flores
(Signature of person mailing)